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Climate Change, Impacts, Future Scenarios and the Role of Transport

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Summary

This working paper is based on research undertaken for the project: *Behavioural Response and Lifestyle Change in Moving to Low Carbon Transport Futures* funded by the *Tyndall Centre for Climate Change Research*. This project is examining the changes that may be required in both the way people travel and how much they travel in order to achieve deep cuts in CO_2 emissions. This paper reports on the first phase of this project, where the aim has been to establish appropriate CO_2 emission targets for the UK transport sector for 2050.

To this end five key studies containing future scenarios for the UK with a focus on carbon emissions have been reviewed. This review was used firstly, to establish two targets for overall reductions in emissions to achieve stabilisation at 550 ppm and 450 ppm of atmospheric CO_2. Secondly to consider the proportion of total emissions that would be attributable to transport in the future. Two approaches were used: as now and an increase in line with forecasts. Finally, the targets and proportionate contributions were used to derive targets for transport sector emissions to be achieved by 2050. These targets range from 8.2 MtC to 25.7 MtC and even the weakest of these targets represents a significant reduction from current emission levels.

1 Introduction

Climate change is an internationally recognised problem. Carbon dioxide is the most important greenhouse gas and is projected to account for 70% of radiative forcing of climate over the next century. The United Nations Framework Convention on Climate Change was agreed in 1992 and at Kyoto in 1997 developed countries agreed to targets which will reduce their overall emissions of six greenhouse gases[1] to 5.2% below 1990 levels over the period 2008-2012. The UK Kyoto commitment is a 12.5% reduction. The UK also has a domestic target of a 20% reduction in carbon dioxide emissions below 1990 levels by 2010 (DETR, 2000a).

It is important to establish the role of transport in achieving reduction targets. In the transport sector CO_2 accounts for 96% of greenhouse gas emissions (GHG). The transport sector is at present the third largest source of carbon dioxide emissions in the UK and is the fastest growing source. The current and projected role of the UK transport sector in producing greenhouse gas emissions is shown in Table 1.1.

Table 1.1 Greenhouse Gas Emissions by End User (MtC)

Sector	Baseline (1990)	2000	2010	2020
Business	90.6	68.6	64.0	64.9
Transport	39.7	41.5	47.8	52.9
Domestic	46.6	42.7	41.5	42.6
Agriculture, forestry and land use	24.8	21.6	19.1	18.0
Public	10.0	8.5	7.8	7.8
Total	211.7	182.9	180.2	186.2

Source: DETR, 2000

Current UK transport policy aims to reduce emissions of GHG's by 5.6 MtC below trend by 2010. This would leave emissions from the sector roughly where they are now. This reduction is dependent on two key policies: the voluntary agreement between the European Commission

[1] The six greenhouse gases are carbon dioxide, methane, nitrous oxide, hydroflurocarbons, perflurocarbons, and sulphur hexafluoride

and European car manufacturers to reduce average carbon dioxide emissions from new cars to 25% below 1995 levels by 2005 (ACEA/EC, 1998), and the Government's 10 Year Plan (DETR, 2000b).

The aim of this paper is to establish appropriate CO_2 emission targets for the UK transport sector in 2050. Evidence on climate change and stabilisation targets is reviewed in Chapters 2 and 3. In Chapter 4 five major studies containing future scenarios are reviewed, with the emphasis on the transport sector. In Chapter 5 two methods are applied to estimate transport's share of emissions in the future. Emission targets are then derived. Chapter 6 offers conclusions.

The next steps in the project will be to develop pathways to achieve the transport targets and a survey tool, which explores the reduction strategies households would select. A main output of the project will be policy recommendations on how the transport sector could achieve reductions and which approaches are most acceptable to households.

2 Climate Change

2.1 The Greenhouse Effect

The Greenhouse effect works in the following way. Radiation from the sun warms the surface of the earth, but when the heat is returned from the earth it has a different wavelength. Because of this it is partly absorbed by the greenhouse gases in the atmosphere and some of it is retained in the Earth-atmosphere system. Hence the more greenhouse gases in the atmosphere the greater the heating effect. The main natural greenhouse gases are water vapour and carbon dioxide. This 'natural' greenhouse effect is a necessary process for human life for without it the earth would be 30°C cooler. Since pre-industrial times there have been increasing concentrations of greenhouse gases from anthropogenic sources. The most important is carbon dioxide, which is projected to account for 70% of radiative forcing of climate over the next century. Prior to the industrial age atmospheric carbon dioxide concentrations were around 280 ppm and had been for several thousand years. Anthropogenic burning of fossil fuels and land use changes have led to a 30% increase in carbon dioxide concentration, which reached 365 ppm in 1998 (Intergovernmental Panel on Climate Change (IPCC), 2001a). Other important greenhouse gases are; nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride (see Table 2.1).

Table 2.1 Other Greenhouse Gases

	Nitrous Oxide	Methane	Hydroflurocarbons	Perflurocarbons	Sulphur Hexafluoride
Anthropogenic source	Woodburning ammonia based fertilisers industrial processes	agriculture – cattle and rice production	Replacement for CFC's	Industry solvents firefighting	Electronic and electrical industries, insulation
Pre-industrial Concentration	About 270 ppb	About 700 ppb	HFC-23 zero	CF4 – 40ppt	0
Post-industrial Concentration	314ppb	1745ppb	HFC-23 14ppt	CF4 – 80ppt	4.2 ppt
Global warming potential (GWP)	310	21	HFC-23 120,000 HFC-41 91	CF_4 5700 C_2F_6 119,000	22,000
Lifetime (years)	114	12	HFC – 23 260 HFC – 41 2.6	CF_4 >50,000 C_2F_6 10,000	3,200

Notes: PPM Parts per million, PPB Parts per billion, PPT Parts per trillion

Source: Grubb *et al,* 1999 and IPCC, 2001a

In order to compare the effects of the different greenhouse gases, the concept of Global Warming Potential (GWP) has been introduced. The GWP is a measure of the gas's relative radiative effect, over a set period of time (typically 100 years), compared with carbon dioxide. The GWP of carbon dioxide is therefore 1. Halocarbons are another important greenhouse gas, however they are ozone damaging gases and have not been covered here because they are being phased out as part of the Montreal Protocol (1987).

The Intergovernmental Panel on Climate Change (IPCC) has undertaken much of the research on climate change. Formed in 1988 and now with almost global participation, its purpose is to "provide authoritative assessments to governments of the state of knowledge concerning climate change" (Grubb et al 1999). It consists of three working groups: Working Group I concerns the science of climate change, Working Group II addresses the impacts of climate change, and Working Group III examines potential responses to climate change. The IPCC has produced three Assessment Reports in 1990, 1995 and 2001.

The latest IPCC (2001a) report shows evidence of an altering climate:

- *"The global average surface temperature has increased over the 20th century by about 0.6^{0}C.*
- *Globally it is very likely[2] that the 1990s was the warmest decade and that 1998 the warmest year in the instrumental record.*
- *Satellite data show that there are very likely to have been decreases of about 10% in the extent of snow cover since the late 1960s.*
- *It is very likely that precipitation has increased by 0.5 to 1 % per decade in the 20th Century over most mid and high latitudes of the Northern Hemisphere continents".*

Although there are reservations about attributing this climate change solely to anthropogenic causes, because of natural variability in the climate record, it is becoming increasingly clear that there is a recognisable human influence on climate change:

[2] Virtually certain (greater than 99% chance if a result is true); very likely (90-99% chance); likely (66-90% chance); medium likelihood (33-66% chance); unlikely (10-33% chance), very unlikely (1-10% chance) (IPCC, 2001a)

"there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (IPCC, 2001a).

2.2 Impacts

The IPCC (IPCC, 2001b) provide examples of observed changes, which include:

- *"Shrinkage of glaciers*
- *Thawing of permafrost*
- *Later freezing and earlier break up of ice on rivers and lakes*
- *The lengthening of mid to high latitude growing seasons*
- *Poleward and altitudinal shifts of plant and animal ranges*
- *The decline of some plant and animal populations*
- *Earlier flowering of trees, emergence of insects, and egg-laying in birds"*

The IPCC also notes the increased frequency of floods and droughts in some areas, but finds that the impact of climatic and socio-economic factors is difficult to quantify. While factors such as land-use change and pollution also act on these systems they conclude that:

"from the collective evidence, there is high confidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems".

2.3 Forecast Emissions, Concentrations and Impacts

In order for future impacts to be assessed a process has to be followed. The first step is to produce forecasts of future emissions. The second step is to estimate the resulting concentrations of CO_2. The third step is to assess the impact of increased concentrations on the rate of climate change. The fourth step is to assess the impacts arising from any resulting changes in climate. The final step is to consider the degree of certainty surrounding these estimates. Here the IPCC assessment is presented. The text necessarily draws heavily on the original source.

(i) Future Greenhouse Gas Emissions

Projections have to be made of the future amounts of greenhouse gases that will be emitted into the atmosphere. These future amounts will be dependent on a large number of factors including population growth, economic growth, and energy use. Because the future cannot be predicted with certainty a wide range and mix of plausible assumptions are used and the resulting futures are called scenarios. Scenarios are not forecasts or predictions but a means of indicating how the future may develop, and they do not have to be considered equally likely.

They consist of two main types, with overlap being a common occurrence.

- Exploratory (descriptive) scenarios examine how the future may occur according to known patterns of change or as extrapolations of past trends.
- Prescriptive (also called normative or backcasting) scenarios work backwards from a defined endpoint, to determine how this endpoint may be achieved.

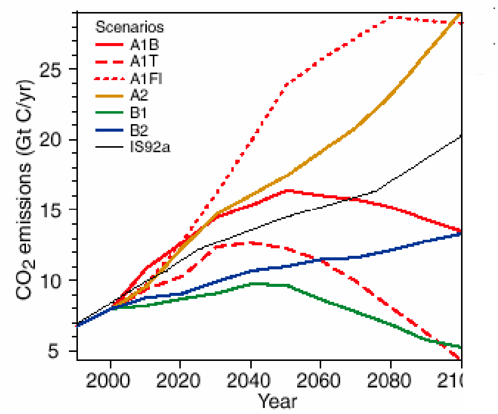
The IPCC has developed exploratory scenarios, which show potential future greenhouse gas emissions up to 2100. Scenarios were developed in 1990 and 1992 and the latest are the Special Report on Emission Scenarios (SRES) (IPCC, 2000), which started development in 1996. The SRES work involved a review of more than 400 emission scenarios, covering the range of greenhouse gases, at both global and regional levels. The key characteristics and driving forces of these emissions were developed into four storylines or scenario groups. The storylines 'cover a wide range of the main demographic, economic and technological driving forces of future greenhouse gas and sulphur emissions' (IPCC, 2001a).

The storylines are A1, A2, B1 and B2. A1 describes a world where: the population increases to around 2050 and then declines; there is rapid economic growth and the introduction of new technologies and convergence amongst regions occurs. The A1 storyline is differentiated by its technological emphasis, covering fossil intensive, (A1FI), non–fossil intensive (A1T) or a balance across all sources (A1B). This has resulted in there effectively being 6 scenario groups. A2 describes a world where the preservation of local identities is important, population growth is high, but economic and technological growth are lower than in the other storylines. Scenario B1 has the same population expansion, peak and decline pattern as A1 but the economy moves towards being more service orientated. From an environmental perspective the emphasis was on the introduction of clean and resource-efficient technologies and global solutions to environmental sustainability. The B2 Storyline has an emphasis on local solutions, with environmental protection and social equity considerations. There is lower population growth than A2 and less economic growth and technological change. The IPCC emphasises that all six scenarios should be considered an equally valid representation of a potential future world.

The scenarios reviewed by SRES are non-mitigation or reference scenarios. They do not include the implementation of the United Nations Framework on Climate Change or the emissions targets from the Kyoto protocol.

The projected CO_2 emissions for the six scenarios to 2100 are illustrated in Figure 2.1. For comparison the IPCC have included one scenario from their 1995 report; IS92a. Figure 2.1 indicates the wide range of potential future emissions, with the highest emissions resulting from the A1FI, a high growth world with reliance on fossil fuels. A2 follows a less steep profile, but results in a similarly high level of emissions. Long-term reductions in emissions are projected with the A1T and B1 scenarios. A1T has the same high growth as the A1FI scenario, however here the reliance is on non-fossil intensive sources of energy. B1 also has the high growth of the A1 scenario but the move towards a service and information economy coupled with an emphasis on global solutions to economic, social and environmental sustainability, results in lower carbon emissions, even though the global solutions do not include specific climate initiatives. The A1B scenario has a balanced source of energy from both non-fossil and fossil intensive sources, and emissions increase and then start to decrease around 2050. The B2 scenario, which has lower growth than A2 and greater consideration of environmental issues increases at a much slower rate than the A2 scenario, though again specific climate initiatives are not included.

Figure 2.1 Projected CO_2 Emissions for different scenarios

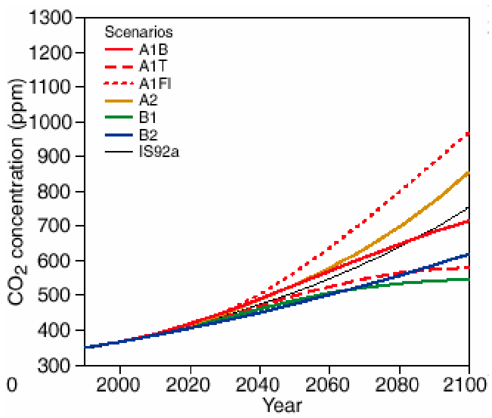


Source: IPCC, 2001a

(ii) Effects of Emissions on Concentration levels

The next step is to estimate the effects these future emission levels will have on future concentration levels. Approximately 50% of the carbon dioxide emitted into the atmosphere is stored in the carbon reservoirs of the oceans and the land rather than in the atmosphere. The carbon is exchanged, but this can take from less than a year, to decades (for exchange with the top layers of the ocean or the biosphere) or millenia (in the deep ocean or long-lived soil pools). This is called the carbon dioxide time lag. Computer models are used which take into account these effects, and the results are shown in Figure 2.2.

Figure 2.2 Projected CO_2 Concentrations for different scenarios



Source: IPCC, 2001a

Depending on the scenario, carbon dioxide concentrations in 2100 are in the range 540-970 ppm. The time lag between projected emissions and concentrations is of relevance in the setting and means of achieving future targets and is discussed further in later chapters.

The IPCC (2001a) has also developed emission profiles for other non-CO_2 Greenhouse gases: Nitrous Oxide, Methane, Hydroflurocarbons, Perflurocarbons and Sulphur Hexafluoride. To summarise A1B, A1T and B1 generally have the smallest increases and A1FI and A2 the largest. Methane changes from 1998 to 2100 are in the range –190 to +1970 ppb, Nitrous Oxide increases by +38 to +144 ppb. The hydroflurocarbons are in the range of a few hundred to a few thousand ppt from insignificant present levels. The Perflurocarbon CF4 is projected to increase in the range 200 to 400 ppt, while Sulphur Hexafluoride is projected to increase in the range 35 to 65 ppt. Increases in non-CO_2 greenhouse gases are potentially important because of their greater global warming potential relative to carbon dioxide.

(iii) Effects of Emissions on Future Climate Change

To determine effects of emissions on future climate and the effects this will have on other related parameters the six SRES scenarios and the IS92a scenario were input into both complex and simple climate models. Depending on the scenario, the globally averaged surface temperature is expected to increase by 1.4 to 5.8 ^{O}C over the period 1990 to 2100 (see Figure 2.3).

This projected rate of warming is greater than the observed changes during the 20th century. This warming will not be spread evenly; land areas are projected to warm more rapidly than the average, particularly those at northern high latitudes in the cold season (IPCC, 2001a). The warming will result in other climatic changes including alterations to precipitation. Sea level (Figure 2.4) will also increase, in the range from 0.09 to 0.88 metres between 1990 and 2100 depending on the scenario; this increase is attributed to thermal expansion and loss of mass of glaciers and ice caps.

Figure 2.3:Temperature Change for different scenarios

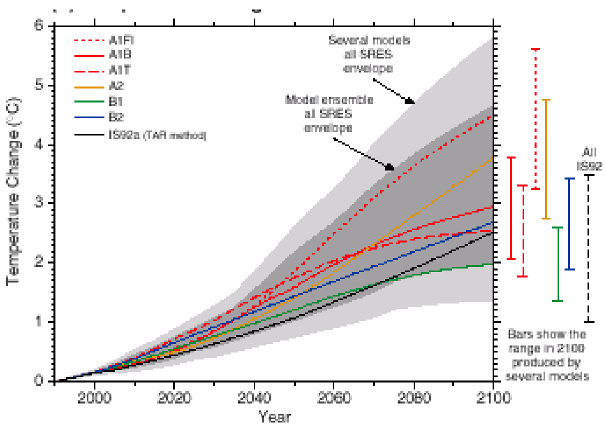
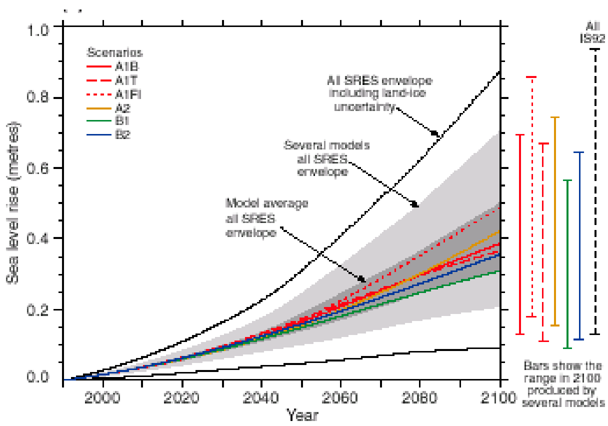


Figure 2.4: Sea Level Rise for different scenarios



Source: IPCC, 2001a

(iv) Impacts of the Changing Climate

To determine the impacts these climate changes will have on human, biological and physical systems, models and a wide range of studies are used. IPCC (2001b) summarises the projected negative effects:

- *"A widespread increase in the risk of flooding for many human settlements.*
- *Decreased water availability for populations in many water-scarce regions, particularly in the sub-tropics.*
- *An increase in the number of people exposed to vector-borne (e.g. malaria) and water-borne (e.g. cholera) diseases, and an increase in heat stress mortality.*
- *A general reduction in potential crop yields in most tropical and sub-tropical regions for most projected increases in temperature".*

The severity of these impacts will vary enormously between regions. There are two reasons for this. Firstly, as mentioned previously, climate change does not affect regions equally, for example in some regions precipitation will increase, in other regions it will decrease. Secondly regions differ in their ability to adapt to climate change, because adaptation is dependent on a number of factors including wealth, technology and infrastructure.

Developing countries will experience the most severe adverse effects:

> *"The impacts of climate change will fall disproportionately upon developing countries and the poor persons within all countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, and other resources".* (IPCC, 2001b).

IPCC (2001b) also expect some positive effects:

- *"Increased potential crop yields in some regions at mid-latitudes for increases in temperature of less than a few ^{0}C.*
- *A potential increase in global timber supply from appropriately managed forests.*
- *Increased water availability for populations in some water-scarce regions.*
- *Reduced winter mortality in mid and high-latitudes".*

There is recognition (Tol, 2002) that for poorer regions any positive benefits will be outweighed by negative impacts, especially as time goes on, and therefore since climate change and greenhouse gas reduction policy is primarily a problem of justice, even countries which could potentially benefit from climate change have a moral obligation to reduce their greenhouse gas emissions.

(v) Scientific Uncertainty

This chapter has examined future projections of emissions, concentrations and impacts and provided an overview of how models are used to determine these projections. The complexity of natural systems and the difficulty in modelling all aspects results in scientific uncertainties. This is acknowledged by the IPCC: "models cannot yet simulate all aspects of climate" (IPCC, 2001a).

This scientific uncertainty can result in suggestions of a 'do nothing' or a 'wait and see' approach. Further reasons for advocating such an approach are concerns over the economic costs and lifestyle changes that could be involved in reducing greenhouse gas emissions and because some people simply do not believe the existing evidence.

Houghton (1997) provides several reasons why doing nothing is not acceptable and these are elaborated on below. The reasons can be divided into two groups. The first group concerns the scientific and economic aspects. Firstly, findings from other scenario building exercises show similar results; for example IIASA-WEC in Nakicenovic *et al* (eds) (1998). There is enough evidence to realise "that the rate of climate change due to increasing greenhouse gases will almost certainly bring substantial deleterious effects" (Houghton, 1997). Secondly there is the carbon dioxide time lag; if emissions are allowed to continue to increase the effects may not be seen in carbon concentrations for centuries. Thirdly there is a human time lag; any major changes required to deal with reductions, for example alterations to infrastructure, will take decades to implement; decisions therefore need to be made soon. Fourthly these economic costs and lifestyle changes are not necessarily negative. Benefits from the introduction of emission reduction measures can include cost savings and improvements in performance through 'no regrets' proposals.

The second group of reasons concerns both inter and intra generational equity. The current use of the world's resources shows no regard for the needs of future generations; dealing with climate change would mean that the world's resources were used in a more sustainable way. There is also the consideration that humans are responsible for the stewardship of the earth. The other key aspect is one of spatial distribution. The developing world is expected to experience the worst effects of climate change; however, it is the developed world that has so far made the greatest contribution to greenhouse gases in the atmosphere. These arguments are just as valid and relevant now as they were in 1997.

3 Stabilisation

There is international recognition of the need to reduce and stabilise emissions, with countries first meeting in 1991 to negotiate a global convention on climate change. The United Nations Framework Convention on Climate Change (UN FCCC) was signed the following year at the Rio Earth Summit.

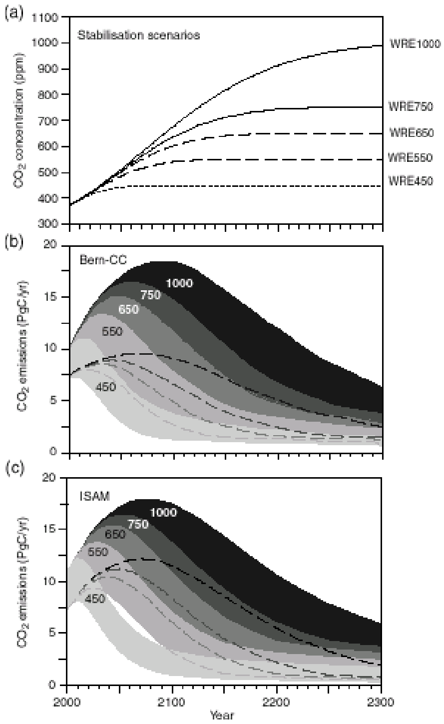
The UN FCCC provides a legal framework to, and principles and objectives for, international action on climate change. It came into force in March 1994 and has now been ratified by 184 countries. Its most significant objective is:

> *"to achieve ...stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".* Article 2 UN FCCC (United Nations, 1992).

The IPCC have modelled the changes in emissions that would be required in order to stabilise concentrations at a range of levels. Figure 3.1 (a) shows WRE CO_2 concentration trajectories, which lead to stabilisation at different levels (Wigley *et al* 1996). These profiles indirectly incorporate economic considerations and are in good agreement with observed carbon dioxide concentrations up to 1999 (IPCC, 2001a). Figures 3.1 (b) and (c) show the implied CO_2 emissions of these stabilisation profiles, when two fast carbon cycle models, Bern-CC and ISAM, are used. The difference in the ranges is due to the two models using different approaches to deal with uncertainties. The ISAM model could be considered to provide "a lower bound on uncertainty"(IPCC, 2001a) while the Bern-CC model could be considered as approaching "an upper bound on uncertainty" (IPCC, 2001a). The details of the models are beyond the scope of this paper (see IPCC, 2001a Chapter 9).

Key points to emerge are firstly that the lower stabilisation targets require early and rapid changes in emissions. Secondly, as many greenhouse gases are long lived, there is a time lag between reductions in emissions and stabilisation. Thirdly, in order to achieve the more demanding targets, substantive cuts in emissions are required. The IPCC (2001a) acknowledges that "stabilisation at 450, 650 or 1,000 ppm would require global anthropogenic emissions to drop below 1990 levels within a few decades, about a century or about two centuries respectively and continue to steadily decrease thereafter" but does not provide detailed figures.

Figure 3.1 Projected CO_2 Emissions permitting stabilisation of atmospheric CO_2 concentrations at different final values



Source: IPCC, 2001a

In order to provide an indication of the level of necessary reductions Figures 3.1 (b) and 3.1 (c) were examined. For each of the concentrations 450, 550, 650, 750 and 1000, the highest and lowest points of the different shaded bands were noted for two timescales 2050 and 2100 (when hidden the lower band is indicated by a hatched line). The two models Bern CC (Figure 3.1b) and ISAM (Figure 3.1c) were considered separately. The resulting emissions range is shown in Table 3.1. The units used in Table 3.1 are Gigatonnes of Carbon per year (GtC/yr), while the units used in Figure 3.1 (b) and (c) are Petagrams of carbon per year (PgC/yr). Two emissions levels for the year 2002, 7.5 GtC and 11.25 GtC, were used to convert the emissions ranges into percentage change from year 2000 levels. 7.5 GtC is the lower figure for the year 2000 in both Figures 3.1(b) and 3.1(c), i.e. for both the Bern-CC and ISAM models, while 11.5 GtC is the highest figure for year 2000 and is shown in Figure 3.1(c), i.e. the ISAM model. The results for the two different 2000 emission scenarios are shown in Tables 3.2 and 3.3.

Table 3.1 Estimated ranges of world CO_2 emissions required for stabilisation at different concentrations (GtC/yr)

CO_2 Concentration ppm	2050		2100	
	Bern-CC	ISAM	Bern-CC	ISAM
450	2.50 to 7.50	2.75 to 8.25	1.25 to 3.50	1.25 to 3.00
550	6.00 to 13.00	8.00 to 13.50	2.50 to 7.50	3.00 to 7.00
650	8.00 to 15.00	10.00 to 15.00	5.00 to 12.50	6.00 to 12.00
750	8.50 to 16.50	11.25 to 16.00	7.50 to 15.00	8.50 to 15.50
1000	8.50 to 17.00	11.50 to 17.00	8.50 to 18.50	11.50 to 17.00

Table 3.2 Percentage Change in World CO_2 emissions from 2000 required by 2050 and 2100 for stabilisation at different concentrations (assuming 2000 emissions are 7.5 GtC/Yr)

CO_2 Concentration (ppm)	2050		2100	
	Bern-CC	ISAM	Bern-CC	ISAM
450	-67 to 0	-63 to +10	-83 to –53	-83 to –60
550	-20 to +73	+7 to +80	-67 to 0	-60 to –7
650	+7 to +100	+33 to +100	-33 to +67	-20 to +60
750	+13 to +120	+50 to +113	0 to +100	+13 to +107
1000	+13 to +127	+53 to +127	+13 to +147	+53 to +127

Table 3.3 Percentage Change in World CO_2 emissions from 2000 required by 2050 and 2100 for stabilisation at different concentrations (assuming 2000 emissions are 11.5 GtC/Yr)

CO_2 Concentration (ppm)	2050		2100	
	Bern-CC	ISAM	Bern-CC	ISAM
450	-78 to -35	-76 to –28	-89 to -70	-89 to –74
550	-48 to +13	-30 to +17	-78 to -35	-74 to –39
650	-30 to +30	-13 to +30	-57 to +9	-48 to +4
750	-26 to +43	-2 to +39	-35 to +30	-26 to +35
1000	-26 to +48	0 to +48	-26 to +61	0 to +48

3.1 Targets

The UN FCCC has stabilisation as its ultimate objective, but does not define a stabilisation concentration, and neither does the IPCC. The political, economic, ethical, social and scientific issues that need consideration make defining a stabilisation target difficult. However, examination of the literature shows key themes and preferences for certain target levels and these are outlined below. The emphasis is on the targets of 350, 450 and 550 ppm. Stabilisation at 750 ppm and 1000 ppm is mentioned in the literature, but no advocates of stabilisation at these figures were found.

In examining the literature two issues of definition emerge. The first regards the units used to describe the stabilisation target. Throughout the literature there was interchange between ppm and ppmv. Since there is no difference between the two units (Seakins, 2002) and ppm is used by the IPCC, ppm is used throughout this report. The second issue relates to the coverage of the stabilisation targets, specifically whether they are solely CO_2 or whether they include other greenhouse gases. In the discussion below the distinction is made.

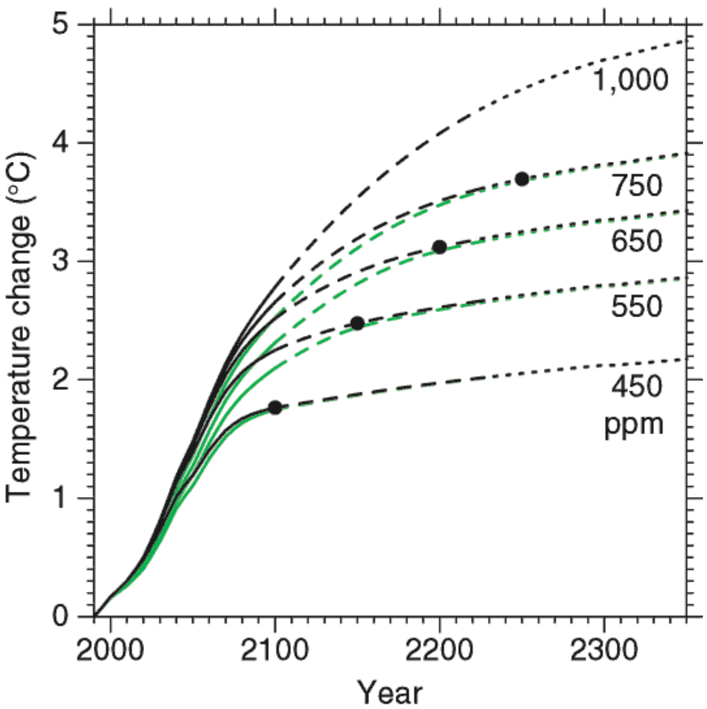
550 ppm

An upper limit of 550 ppm carbon dioxide has been advocated by both the EC (1996) and the Royal Commission on Environmental Pollution (RCEP, 2000). This recommendation refers solely to carbon dioxide though it is acknowledged that other greenhouse gases are also important contributors. Since industrialisation the increase in the concentration of other greenhouse gases has contributed the equivalent of 50 ppm carbon dioxide (RCEP, 2000). The RCEP (2000) also recommended continuous review of targets.

The IPCC (2001a) show that stabilisation of carbon dioxide equivalence (including other greenhouse gases) at 550 ppm would result in a temperature change greater than 2^0C (see Figure 3.2). In developing the model the IPCC used two sets of carbon dioxide stabilisation profiles: the WRE profiles developed by Wigley *et al* (1996) and the S profiles (Enting *et al* 1994). The WRE profiles shown as a black dotted line in Figure 3.2 include economic considerations and correspond with observed carbon dioxide concentrations up to 1999. The S profiles shown as the grey dotted line are the original stabilisation profiles, though the IPCC considers them unrealistic because the emissions and concentration values they require are lower than those observed during the 1990s. The black dots in Figure 3.2 indicate the year in which CO_2 stabilisation is achieved.

The WMO/ICSU/UNEP Advisory Group on Greenhouse Gases (Rijsberman and Swart (eds) 1990) state that a 2^0C increase in temperature is a high risk situation and that “temperature increases beyond 1.0^0C may elicit rapid, unpredictable, and non-linear responses that could lead to extensive ecosystem damage”. Since stabilisation at 550 ppm would result in a greater than a 2^0C increase in temperature, doubts could be raised over whether the UN FCCC objective of “stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous atmospheric interference with the climate system” would be achieved if a 550 ppm stabilisation target is set.

Figure 3.2 Simple model results: Projected global mean temperature changes when the concentration of CO_2 is stabilised following the WRE profiles



Source: IPCC, 2001a

Targets lower than 550 ppm

The Global Commons Institute (GCI) (2002) expresses the view that given the state of uncertainty as to the appropriate target level it would be unwise to set the level too high as this would ‘lockout’ lower target levels. The GCI (2002) suggest that if a target of 550 ppm were set, but later evidence pointed to a much lower target of 350 ppm, this would not be achievable after 2005. However, if the initial target was 450 ppm, then this could if necessary be switched to 350 ppm up to 2015. The GCI (2002) believes that 350 ppm is a desirable target and if this were implemented then there is a good chance that "large-scale damage to the world economy, human lives and natural ecosystems can be averted". It regards 450 ppm "as an upper limit for consideration; under which there is a chance that damage, though, serious will be containable". They therefore argue for a lower target on the combined grounds of scientific uncertainty and the precautionary principle. However it is not clear whether they are referring to carbon dioxide alone or overall greenhouse gases.

Others advocating lower limits include Azar and Rodhe (1997) who suggest that stabilisation of carbon dioxide should be achieved in the 350 ppm and 450 ppm range. They acknowledge that policies are also needed to constrain emissions of other greenhouses gases. Alcamo and Kreileman (1996) also suggest that "stabilising carbon dioxide alone in the atmosphere below 450 ppm substantially reduces climate impacts", and that controlling non-CO_2 emissions (i.e. other GHGs) in addition to CO_2 emissions is an effective policy to slow temperature increase.

Houghton (1997) initially examines carbon dioxide stabilisation alone and highlights the economic considerations, recognising that stabilisation below 400 ppm would require an immediate drastic reduction in emissions, and this would come at a high economic cost, which is considered to breach the UN FCCC (United Nations 1992) requirement for "economic development to proceed in a sustainable manner". Stabilisation in the range of 400 ppm and 550 ppm is recommended. However, it is also suggested that non-CO_2 gases could contribute the equivalent of 45 ppm carbon dioxide and therefore 500 ppm CO_2 should be considered the stabilisation limit. Serchuk and Means (1997) suggest that 550 ppm is considered an appropriate target because more ambitious targets would precipitate "economic havoc". It is not clear if carbon dioxide or carbon dioxide and other greenhouse gases are referred to here.

To summarise the most common stabilisation target is 550 ppm carbon dioxide. It is generally recognised that additional measures will be needed to reduce other non-CO_2 greenhouse gases. If non-CO_2 greenhouse gases are also included then the 'safe' target for carbon dioxide alone would have to be lower than 550 ppm.

However it is not just the stabilisation target that is the subject of much debate. Other important connected issues include the expected role of different countries and the timescales the reductions should operate on.

Regarding the role of the different countries, it is widely acknowledged that developed countries should take the lead in reducing emissions, because of both their past contribution to emissions and their present abilities to reduce emissions (UN FCCC article 3.1). However in the longer term it is recognised that, in order for emissions reduction to be successful, both developed and developing countries have a role to play (RCEP, 2000). For decisions regarding timescales, there are economic considerations. Opposing views are:

i. early achievement of stabilisation targets would be costly
ii. starting action earlier would bring benefits due to:
    - 'learning while doing' effects
    - no regrets measures
    - the widespread use of low carbon technologies bringing down costs and encouraging further development.

There are various suggestions put forward to deal with these issues, for example allocations could be inversely related to past emissions or alternatively allocations to developing nations could be linked to their economic growth. One approach that has received much recognition is the Contraction and Convergence approach.

3.2 The Contraction and Convergence approach

The Contraction and Convergence approach aims to reduce greenhouse gas emissions to an acceptable level. It is a two stage process: firstly convergence would occur; the emission levels of the developing nations would rise, and emission levels of developed countries would fall until an agreed point for convergence was reached. At this point all countries would have the same per capita emissions. Secondly all countries would reduce their emission levels (contraction). International negotiations would determine the upper limit of the concentration of greenhouse gases, and the date when convergence would occur.

A significant party in the promotion of this approach is the Global Commons Institute (GCI) whose Contraction and Convergence campaign has received backing from GLOBE, an international organisation of environmentally concerned parliamentarians, including from the UK Rt Hon. Michael Meacher MP, Minister for the Environment, Sir John Gummer, Former Secretary of State for the Environment, and the Green Party.

The RCEP have used the contraction and convergence approach to estimate the level of reductions that would be required in the UK by 2050 and 2100 for different upper limits of carbon dioxide concentration. The reductions required for stabilisation at different levels are shown below in Table 3.4.

Table 3.4 Contraction and Convergence : implications for UK carbon dioxide emissions

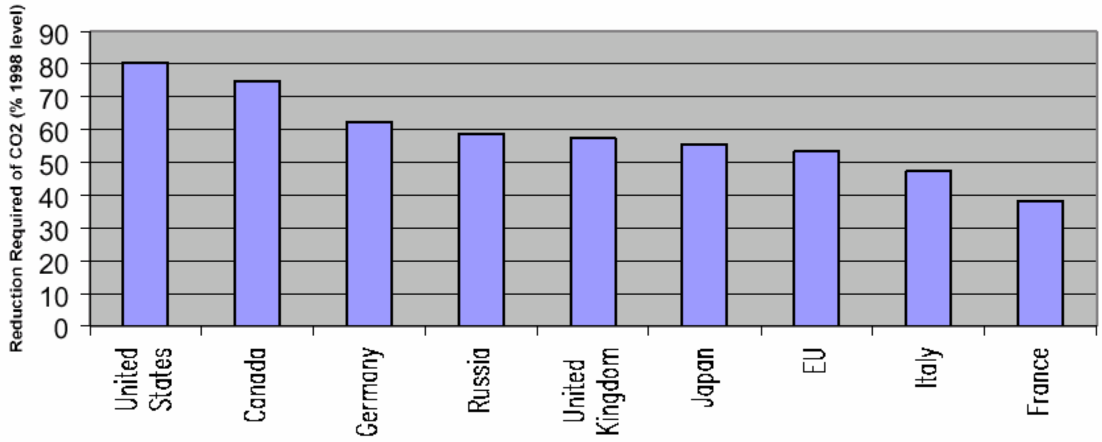
Maximum atmospheric concentration ppm	Permissible UK emissions in 2050 (% of 1997 level)	Permissible UK emissions in 2100 (% of 1997 level)
450	21	11
550	42	23
750	56	47
1000	58	61

Source: RCEP, 2000

Therefore if carbon dioxide emissions were to be stabilised at 550 ppm, emissions would have to be reduced by almost 60% from 1997 levels by 2050 and by almost 80% from 1997 levels by 2100. The RCEP therefore recommends that "The Government should now adopt a strategy which puts the UK on a path to reducing carbon dioxide emissions by some 60% from current levels by about 2050" (RCEP, 2000).

The Inter-departmental Analysts Group (IAG) (2002) has used the contraction and convergence approach to explore the role of other countries if the contraction and convergence approach was utilised. This is shown in Figure 3.3. A key point is the 80% reduction that would be expected from the USA.

Figure 3.3 CO_2 reductions required by 2050 to achieve stabilisation at 550 ppm



Source: IAG, 2002

The RCEP (2000) recognises that some developed nations may be wary of this approach because it involves very large reductions in their emissions, and suggests that this approach is made more feasible by the introduction of flexibility, which would allow countries to trade their emission quotas. However any form of trading needs to be 'transparent, monitored and regulated' and backed by enforceable penalties if nations emit more than their entitlement.

3.3 Conclusions

The likelihood of other countries adhering to the contraction and convergence approach will be an important consideration for the UK Government in deciding whether or not to follow such an approach. The recent Energy White Paper (2003) indicates that the UK government has now adopted the 60% target as an aim. However, the PIU (2002) states that greenhouse gases are global pollutants and that the UK should not incur abatement costs, and risk harming competitiveness, unless other countries are also willing to do so.

For this project the RCEP targets (Table 3.4) will be used. There are several reasons for this. Firstly the stabilisation targets of 450 ppm and 550 ppm are those with greatest support in the literature. Secondly contraction and convergence has substantial political and scientific backing. Thirdly since this project is to be undertaken in the UK there is a need for UK based targets. Fourthly the Royal Commission on Environmental Pollution is a long established, influential body, and these target figures are already being used in policy work for the UK. Hence the use of these figures will ensure consistency and enable comparison. In addition even if the contraction and convergence approach is not followed, the emissions reductions required for the UK are likely to be substantial.

4 Scenarios

In this Chapter a review is made of five studies which utilise the RCEP recommendation of a 60% reduction target and detail the role that transport is expected to play. The five studies are:

- The RCEP (2000) Twenty Second Report: Energy the Changing Climate

- The Carbon Trust (2001): Draft Strategic Framework[3]
- The Policy and Innovation Unit (PIU) (2002): The Energy Review
- The Interdepartmental Analysts Group (IAG) (2002): Long Term reductions in Greenhouse Gas Emissions in the UK
- Future Energy Solutions from AEA Technology in collaboration with the Imperial College Centre for Energy Policy and Technology (ICCEPT): Options for a Low Carbon Future (AEA Technology, 2002)[4]

The Carbon Trust (2001), the RCEP (2000), and the IAG all develop scenarios to show how a 2050 world may look. The PIU (2002) use the Foresight (1999a) scenarios as the base for their work. The IAG and the AEA Technology/ICCEPT collaboration also consider the Foresight work. A description of the Foresight scenarios is therefore provided in section 4.3 as background information.

All the studies recognise the need for substantial change in order to achieve a 60% reduction in carbon dioxide emissions by 2050. In 1997 carbon dioxide emissions were 148 MtC on a UNECE basis and either 149 or 153 MtC on an IPCC basis (depending on whether carbon removal is included) (DEFRA, 2002). UNECE excludes land use change and also international shipping in UK ports, but includes aviation emissions below 1,000 metres to cover take off and landing cycles. The IPCC figure includes land use change and all emissions from domestic aviation and shipping, but excludes international marine and aviation bunker fuels. For this project it was decided to use the UNECE figures, since these are the figures used in Transport Statistics Great Britain (DETR, 2001), which will be an important source of information for Phase 2 of the project. Using the 148 MtC figure, for a 60% reduction to be achieved, carbon dioxide emissions would need to fall to around 59.2 MtC by 2050.

For each study the general scenarios involved are first outlined and then the implications for transport are assessed.

4.1 Royal Commission on Environmental Pollution Scenarios

The RCEP's (2000) scenarios are considered to be prescriptive or backcasting scenarios, because they work backwards from the 60% target. The scenarios have common features in that all assume a move away from the current patterns of energy use, but fossil fuels remain the most important source of energy. It is assumed that oil is still the primary source of fuel in the transport sector. The main differences lie in assumptions relating to demand for energy and energy sources. The key points from the four scenarios are detailed in Table 4.1 and are discussed below. Energy demand is fixed at 1998 levels for scenario 1 and falls from 1998 levels in the other scenarios. Stabilisation at 1998 levels would be a departure from previous trends. If final energy demand were to continue to rise at just over 0.5% per annum, which has been the mean rate over the last 10 years, it would be 30% higher in 2050 than it is now (DTI, 1999).

Scenario 1

Scenario 1 assumes that demand for energy has stabilised at 1998 levels. It is envisaged that stabilisation could be achieved by relatively minor changes in energy policy, including gradual price increases. This scenario requires the highest energy supply. 106 GW per annum would be supplied from fossil fuel sources, which is universal for all four scenarios. 105 GW would be

[3] The Draft Strategic Framework is used rather than the Strategic Framework since information about the scenarios and baseline projections is provided in greater detail

[4] The AEA Technology/ ICCEPT work examines three emission reductions a 45%, a 60% and a 70% reduction from 2000 levels.

supplied from a combination of renewables and either nuclear power or large fossil fuel stations with the recovery and disposal of carbon dioxide. This scenario sees the greatest use of renewables.

Table 4.1 Energy Use in the RCEP four scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
% reduction in CO_2 emissions from 1997 levels	**57**	**60**	**60**	**60**
Demand (%) reduction from 1998 final consumption				
Low-grade heat	0	50	50	66
High-grade heat	0	25	25	33
Electricity	0	25	25	33
Transport	0	25	25	33
Total	**0**	**36**	**36**	**47**
Supply (GW) annual average rate				
Fossil fuels	106	106	106	106
Intermittent renewables	34	26	16	16
Other renewables	19	19	9	4
Baseload stations (either nuclear or fossil fuel with carbon sequestration)	52	0	19	0
Total Supply	211	151	150	136

Source: adapted from RCEP, 2000

Scenarios 2 and 3

Scenarios 2 and 3 both have an overall reduction in energy demand to 36% below the 1998 level. This reduction assumes the full implementation of energy efficiency policies and that the price of energy will increase gradually but substantially through taxation. The revenue raised would primarily be used to fund energy efficiency improvements. The means of supplying non-fossil fuel energy differs between the two scenarios; in Scenario 2 demand would be met by the use of renewables while Scenario 3 would see a combination of renewables and either nuclear power stations or large fossil fuel power stations with carbon sequestration.

Scenario 4

Scenario 4 has an even greater reduction in demand: 47% from 1998 levels, or a 59% reduction from 2050 levels if current trends were to continue. Renewables are used rather than nuclear or fossil fuels with carbon sequestration, but because the energy demand is much lower, the use of renewables is actually lower than in the other three scenarios. Overall there is limited detail of what exactly scenario 4 would entail, and no mention of the role of transport. The RCEP acknowledges that energy reductions on this scale would be difficult to achieve, and that there might have to be some reduction or redefinition of living standards. This would have to be weighed against the fact that less investment in energy installations would be required.

The role of transport can be divided into two stages: 1) the role of transport in ensuring energy demand is stabilised at 1998 levels (this is assumed to be the same for all four scenarios) and 2) the demand reduction from 1998 levels indicated in Table 4.1 (this varies among the four scenarios).

To ensure energy demand remains at 1998 levels the RCEP suggest a wide range of measures across all sectors. Transport measures include: congestion charging schemes, a wider differential in Vehicle Excise Duty and measures to ensure that the ACEA voluntary agreement is successful. The contribution from these measures is not quantified.

To achieve the demand reductions from 1998 levels indicated in Table 4.1, the RCEP, depending on the scenario, considers different transport measures. These are detailed below. The contribution from these measures is not quantified.

Scenario 1
Growth in the use of private cars and the quantity of air travel is expected to be offset by substantial improvements in the efficiency of vehicles and aircraft. The majority of the UK car fleet will run on fuel cells (the hydrogen for these cells would be obtained from oil or gas).

Scenario 2 and 3
Growth in road traffic and air travel would stabilise in the early decades of the century and then fall slightly. Again fuel cells will be used in most cars. However there is greater emphasis on public transport than in Scenario 1, with a higher proportion of journeys made by public transport than at present. There are alterations to mobility and lifestyles too, with the impact of electronic communication halting the growth in personal mobility. The journey to work is altered with a large proportion of the population working from home or near home locations.

Scenario 4
There is no mention as to how a 33% reduction from 1998 levels will be achieved, though as mentioned earlier the RCEP acknowledges that it is difficult to envisage how the total reduction in energy demand that this scenario requires could be achieved, and that some reduction or redefinition of living standards may be necessary.

In order to obtain an estimate of the contribution from transport in MtC, it is assumed here that demand reductions in energy consumption lead to equivalent reduction in carbon emissions. The percentage demand reductions from 1998 final consumption (Table 4.1) were applied to the UNECE end user figures for 1998 (DEFRA, 2002). For comparison purposes the UK Climate Change figures for end user emissions in transport for 2000 (DETR, 2000a) were also utilised.

Table 4.2 Change in transport CO_2 emissions (MtC) in the four RCEP scenarios

Change in MtC	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Demand reduction (%) from 1998 final consumption	0.0%	-25.0%	-25.0%	-33.0%
End user CO_2 emissions from transport in 1998 (MtC). Source UNECE (DEFRA, 2002)	38.8	38.8	38.8	38.8
Reduction in CO_2 transport emissions (MtC)	0.0	9.7	9.7	12.8
End user CO_2 emissions from transport in 2000 (MtC) Source UK Climate Change Programme (DETR, 2000)	40.0	40.0	40.0	40.0
Reduction in CO_2 transport emissions (MtC)	0.0	10.0	10.0	13.2

The RCEP scenarios suggest ways of achieving a 60% reduction in CO_2 emissions with less than equivalent reductions in demand through the use of different energy sources. However reductions in demand in the transport sector of 25% and 33% are envisaged.

4.2 The Carbon Trust

The Carbon Trust in their Draft Strategic Framework use an extrapolatory approach to develop two baseline projections for a 2050 world. A backcasting approach is then used to develop four scenarios which achieve varying carbon dioxide reductions from 1997 levels.

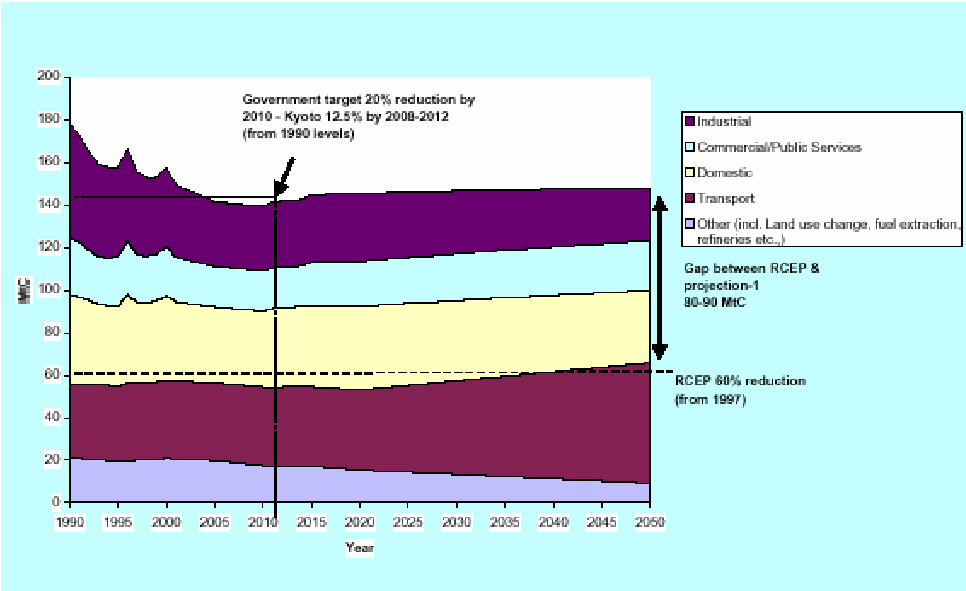
The two baseline projections are based on the Government's energy predictions to 2020 with trends continued to 2050. Both projections also assume: no new nuclear power stations will be built; a sharp rise in gas consumption to 2020 which stays approximately the same to 2050; the steady decline in coal to be replaced by gas and some renewables. The key differences between the projections are shown in Table 4.3.

Table 4.3 Differences between Baseline Projection 1 and Baseline Projection 2

Baseline Projection 1	Baseline Projection 2
Only partial implementation of the measures included in the Climate Change Programme and these measures will not be renewed after 2020.	Full implementation of the measures included in the climate change programme. The measures will continue on the same scale to 2050.
Lower energy efficiency improvements than in projection 2 (not quantified).	Energy Efficiency improves at a faster rate than in projection 1 (not quantified).
New road build.	No new road build.
Unconstrained road transport growth.	Modal shifts and reductions in car use. Fewer HGVs
Fuel efficiency for cars would met the EC Voluntary agreement (ACEA, 1998) but other improvements would be offset by increased vehicle size.	Development and use of advanced internal combustion engines.
Renewables provide 15% of electricity generation by 2050.	Renewables provide 22% of electricity generation by 2050.

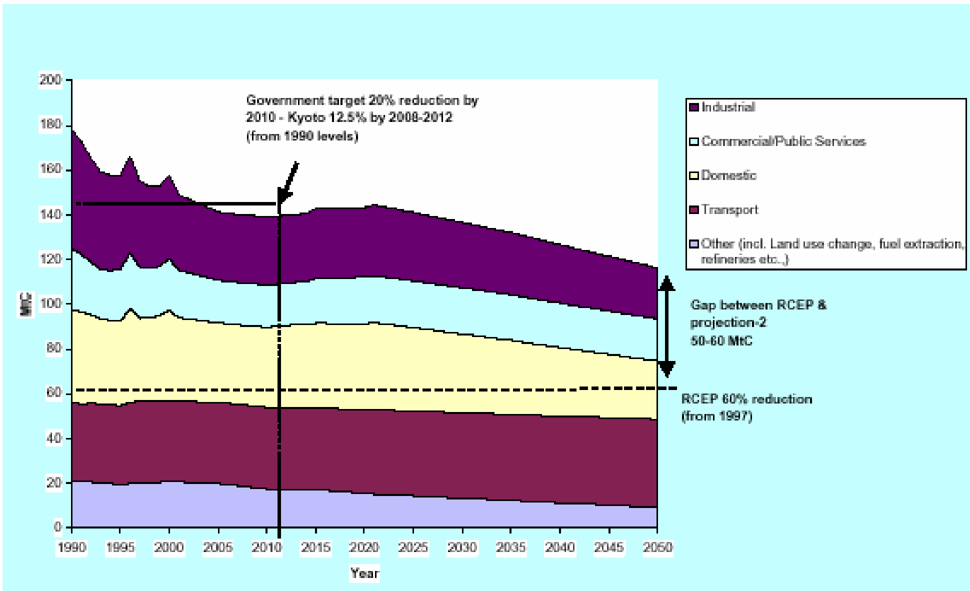
Baseline Projection 1 produces 150 MtC and Baseline Projection 2 120 MtC per annum in 2050. The gap to the RCEP 60% reduction is larger in Baseline Projection 1 (80-90 MtC) than it is in Baseline Projection 2 (50-60 MtC). This can be seen in Figures 4.1 and 4.2. The Carbon Trust assumes that emissions in 1997 are 157 MtC, the source of this figure is not provided. Transport makes the highest contribution to carbon dioxide emissions in both baseline projections.

Figure 4.1 UK CO_2 emissions by sector (2000-2050): Baseline Projection 1



Source: The Carbon Trust, 2001

Figure 4.2 UK CO_2 emissions by sector (2000-2050): Baseline Projection 2



Source: The Carbon Trust, 2001

The Carbon Trust developed four scenarios, which achieve varying carbon dioxide emission reductions. These are:

- Low Carbon Market - the market/suppliers drives take up of low carbon technologies because technical and economic restraints have been removed.
- Low Carbon Government - the Government drives take up by removing regulatory constraints and setting additional standards.

- Low Carbon Consumers - here informational and behavioural constraints are removed and consumer demand for low carbon technologies is the key driver.
- Low Carbon Future - where the main technical, economic, regulatory, informational and behavioural constraints are all removed.

The measures, which bring about carbon savings within these scenarios include:

- Increased Energy Efficiency
  - Domestic
  - Commercial
  - Industrial
  - Fuel cell efficiency in transport
- Combined Heat and Power (CHP)
- Widescale introduction of renewables
- Hydrogen production from renewables and hydrogen use in transport and space heating

Depending on the baseline projection and the scenario, the contribution from each of these measures varies. The roles of the different measures for Baseline Projections 1 and 2 are illustrated in Tables 4.4 and 4.5.

Table 4.4 UK Carbon Emission Reductions by Technology (2050) Baseline Projection 1

Technology Options	Scenarios: Low Carbon Markets	Low Carbon Government	Low Carbon Consumers	Low Carbon Future
	Carbon savings in 2050 cf. baseline projection (MtC)			
Energy Efficiency				
Domestic	8.44	12.05	16.49	25.10
Commercial	1.38	2.76	1.49	4.37
Industrial	3.49	4.38	2.13	4.85
Fuel Cell Efficiency in Transport	4.13	5.23	4.10	8.40
CHP				
Domestic	0.40	0.62	0.09	0.73
Commercial	0.52	0.93	0.19	1.54
Industrial	2.46	3.87	1.55	4.55
TOTAL ENERGY EFFICIENCY	**20.82**	**29.84**	**26.03**	**49.55**
Renewables				
Municipal Solid Waste	0.88	0.94	0.89	1.03
Landfill Gas	0.66	0.71	0.66	0.77
Wave	0.45	0.48	0.45	0.52
Tidal	0.43	0.46	0.44	0.50
Onshore Wind	0.96	1.12	0.89	1.50
Offshore Wind	1.76	2.39	1.76	3.07
Energy Crops	1.84	3.02	2.03	4.58
Solar Photovoltaics	3.05	4.16	3.15	8.85
Hydro (Large Scale)	0.27	0.29	0.28	0.32
Hydro (Small Scale)	0.14	0.15	0.14	0.16
TOTAL RENEWABLE (FOR ELECTRICITY GENERATION)	**10.44**	**13.72**	**10.68**	**21.30**
CARBON SEQUESTRATION	**1.06**	**1.51**	0.30	**3.11**
Hydrogen				
Hydrogen (for Transport)	5.95	8.50	4.44	14.96
Hydrogen (Space Heating)	7.00	8.28	8.76	14.44
TOTAL HYDROGEN (FROM RENEWABLES)	**12.94**	**16.78**	**13.20**	**29.39**
TOTAL SAVINGS MtC (relative to BASELINE PROJECTION)	**45.27**	**61.86**	**50.21**	**103.36**
% TOTAL SAVINGS (relative to 1997)	**34%**	**45%**	**37%**	**72%**

Source: The Carbon Trust, 2001

Table 4.5 UK Carbon Emission Reductions by Technology (2050) Baseline Projection 2

	Scenarios			
Technology Options	**Low Carbon Markets**	**Low Carbon Government**	**Low Carbon Consumers**	**Low Carbon Future**
	Carbon savings in 2050 cf. baseline projection (MtC)			
Technology Options				
Energy Efficiency				
Domestic	6.14	8.78	11.22	18.28
Commercial	0.98	1.96	0.85	3.11
Industrial	2.50	3.15	1.28	3.49
Fuel Cell Efficiency in Transport	2.55	3.64	2.51	6.82
CHP				
Domestic	0.39	0.60	0.09	0.71
Commercial	0.49	0.88	0.18	1.46
Industrial	2.34	3.69	1.48	4.34
TOTAL ENERGY EFFICIENCY	**15.39**	**22.70**	**17.61**	**38.20**
Renewables				
Municipal Solid Waste	0.52	0.62	0.53	0.75
Landfill Gas	0.39	0.46	0.40	0.56
Wave	0.26	0.32	0.27	0.38
Tidal	0.26	0.30	0.26	0.37
Onshore Wind	0.57	0.73	0.53	1.10
Offshore Wind	1.04	1.57	1.05	2.24
Energy Crops	1.08	1.98	1.21	3.35
Solar Photovoltaics	1.80	2.73	1.88	6.47
Hydro (Large Scale)	0.16	0.19	0.16	0.23
Hydro (Small Scale)	0.08	0.10	0.08	0.12
TOTAL RENEWABLE (FOR ELECTRICITY GENERATION)	**6.16**	**9.00**	**6.37**	**15.59**
CARBON SEQUESTRATION	**1.06**	**1.51**	**0.30**	**3.11**
Hydrogen				
Hydrogen (for Transport)	5.95	8.50	4.44	14.96
Hydrogen (Space Heating)	5.01	6.02	6.40	10.89
TOTAL HYDROGEN (FROM RENEWABLES)	**10.95**	**14.52**	**10.84**	**25.84**
TOTAL SAVINGS MtC (relative to BASELINE PROJECTION)	**33.56**	**47.74**	**35.12**	**82.74**
% TOTAL SAVINGS (relative to 1997)	**47%**	**56%**	**48%**	**79%**

Source: The Carbon Trust, 2001

The Low Carbon Futures scenario receives a greater than 60% reduction for both of its baseline projections. Baseline projection 1 achieves a 72% reduction from 1997 levels and baseline projection 2 achieves a 79% reduction from 1997 levels. However the Low Carbon Futures scenario assumes that the main technical, economic, regulatory, informational, and behavioural constraints to the development of a low carbon world have been removed. It is a highly optimistic scenario.

Baseline Projection 1 used an unconstrained National Road Traffic Forecast (NRTF) model run to determine road transport energy demand (The Carbon Trust, 2001). New road build was also included. It was assumed that efficiency improvements in vehicles would meet the EU voluntary agreement (ACEA/EC, 1998) but not develop further. In terms of emission reductions the role of the transport sector is limited to the technological options of hydrogen and fuel cells (Table 4.6).

Table 4.6 UK Transport Carbon Emission Reduction by Technology and Scenario (MtC)

	Low Carbon Markets	Low Carbon Government	Low Carbon Consumers	Low Carbon Futures
Baseline Projection 1 Fuel cell efficiency in Transport	4.13	5.23	4.10	8.40
Baseline Projection 2 Fuel cell efficiency in Transport	2.55	3.64	2.51	6.82
Baseline Projection 1 Hydrogen from renewables (for transport)	5.95	8.50	4.44	14.96
Baseline Projection 2 Hydrogen from renewables (for transport)	5.95	8.50	4.44	14.96

The hydrogen is assumed to come from renewable sources. No information is provided on the proportion of vehicles using fuel cells. Since a greater than 60% reduction across all sectors may be achieved without alterations to transport demand under the low carbon futures scenario (Table 4.4) the Carbon Trust concludes that:

> *"the RCEP target is still within reach even if growth in the transport sector is unconstrained"*

Baseline Projection 2 uses the NRTF central growth scenario. The Carbon Trust assumes that this scenario:

> *"significantly constrains growth (in terms of road travel) due to an assumption of no new road build and assumptions including the development and use of advanced internal combustion engines in vehicles, modal shifts, reductions in car use and fewer HGVs".* (The Carbon Trust, 2001).

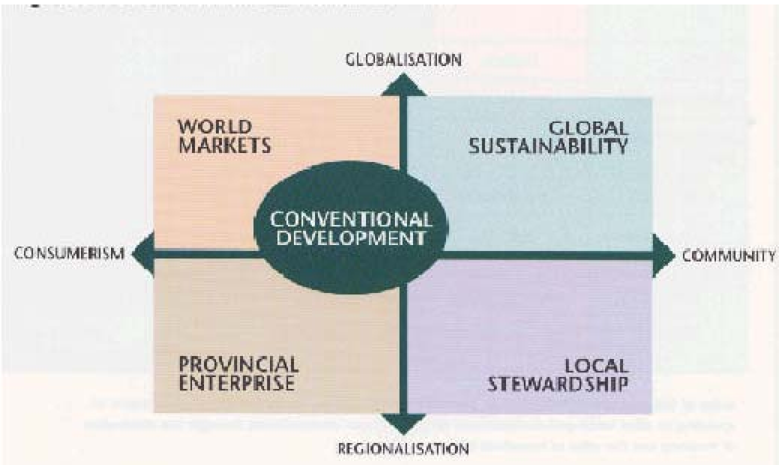
Details are not provided about these assumptions but it is suggested that they could result in savings of 20-30 MtC by 2050. It is not clear how these relate to the technological savings described in Table 4.6.

Baseline 2 uses the same technology options, but since it does not assume unconstrained traffic growth the contribution from fuel cell efficiency reductions does not have to be as high as Baseline 1 (Table 4.6).

4.3 Foresight Scenarios

Both the PIU (2002) and the IAG (2002) utilise the Foresight scenarios in their descriptions of the 60% reduction, therefore a brief overview of the Foresight scenarios is provided here. The Foresight scenarios were developed in 1999 by the DTI in cooperation with SPRU (Foresight, 1999a). There are four scenarios: World Markets; Provincial Enterprise; Global Sustainability; and Local Stewardship, which are closely aligned with the SRES scenario groups of A1, A2, B1 and B2, respectively. The scenarios are set within the context of two dimensions of change: social values and governance systems, with social values forming the X axis and governance systems forming the Y axis (see Figure 4.3). There is no business as usual scenario but as can be seen in Figure 4.3 World Markets could be considered to most closely resemble conventional development.

Figure 4.3 Four Contextual UK Futures scenarios



Source: Foresight, 1999a

Foresight (1999a) provides a synopsis of the key themes of the four scenarios:

World Markets is “a world defined by emphasis on private consumption and a highly developed and integrated world trading system”.

Global Sustainability is “a world in which social and ecological values are more pronounced and in which the greater effectiveness of global institutions is manifested through stronger collective action in dealing with environmental problems”.

Provincial Enterprise is “a world of private consumption values coupled with a capacity for lower level policy-making systems to assert local, regional and national concerns and priorities”.

Local Stewardship is “a world where stronger local and regional governments allow social and ecological values to be demonstrated to a greater degree at local level”.

A summary of the key indicators for the four scenarios is detailed in Table 4.7.

Table 4.7 Key Indicators for the Scenarios

	World Markets	Provincial Enterprise	Global Sustainability	Local Stewardship
Values	Consumerist	Individualist	Conservationist	Conservative
Governance	Globalisation	National	Globalisation	Regional/National
UK GDP	3%	1.5%	2%	1%
Fast Growing sectors	Health care, leisure, distribution, financial services	Private health care and education, maintenance services, defences	Renewable energy, household services, information intensive business services	Small-scale, intensive manufacturing, locally based financial and other services, small-scale agriculture
Declining sectors	Manufacturing, agriculture	High-tech specialised services, financial services	Fossil fuel-based power systems, resource intensive agriculture and manufacturing	Retailing, leisure and tourism
Equity	Declines	Declines	Improves	Improves
ISEW (per year)	-2%	-4%	+2%	+1%
Environmental State				
Air quality	General decline	Declines	Improvement	Mixed
Water quality	Mixed	Deteriorates	Improvement	General Improvement
Biodiversity	Under Pressure	Deterioration	Stable	Improves
Climate	Emissions trading	Management fails	Strong climate management	Weak management

ISEW (Index of Sustainable Economic Welfare) - the ISEW adjusts GDP per capita income to take account of spending to offset social and environmental costs, long-term environmental damage, the distribution of incomes and the value of economic labour

(Source: Foresight, 1999a).

A separate Foresight report on Actions for Sustainable Transport (Foresight, 1999b) looked at the implications of these scenarios on the transportation and travel business over the next 20-30 years. Key themes from this analysis for each of the scenarios are detailed below. As with the Foresight scenarios there was no business as usual scenario, though again World Markets could be considered to be most like conventional development.

World Markets

- Rapid growth of personal car use will continue
- Cars are predominantly based on the internal combustion engine, fuelled by petroleum products
- In major metropolitan areas battery, hybrid and fuel cell electric vehicles will be used
- Congestion will increase, but will be partially relieved by the greater use of in-car transport telematics
- Energy prices will be low
- Use of the internet for work and shopping will increase as congestion worsens
- Greater use will be made of inter-city rail, although its economics will be driven by the needs of business passengers

- There is a relatively weak planning system.

Provincial Enterprise
- High car dependency
- Little additional provision for public transport
- Low investment results in the average age of the car stock becoming greater
- Investments in infrastructure are low
- Congestion and accidents increase.

Global Sustainability
- Rapid market penetration of low emissions hybrid and fuel cell passenger vehicles
- Heavy investment in public and mass transit systems
- From 2010 transport telematics begin to substitute for mobility
- Air traffic continues to grow
- Road traffic growth continues but at a much slower rate than the past.

Local Stewardship
- Cost of transport increases due to increased energy prices and the internalisation of costs
- There is an emphasis on avoiding the need to travel
- Local planning systems ensure that facilities are available close to people's homes
- Car ownership and car use reduced by the use of car-sharing, home deliveries and traffic management schemes
- Shorter journeys are made using alternative energy technology vehicles
- Longer journeys are made using mass transit systems.

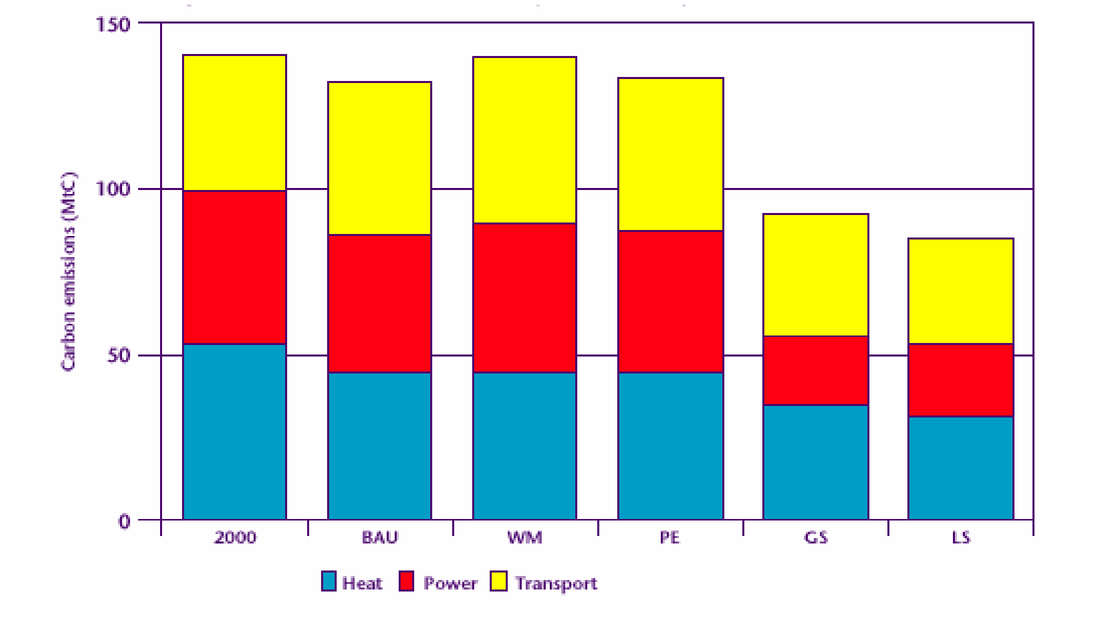
Two studies, which use the Foresight scenarios in exploring pathways to a 60% cut in CO_2 emissions are: the Policy and Innovation Unit Energy Review and the Inter-departmental Analysts Group Long term reductions in Greenhouse Gas Emissions in the UK. These are considered below.

4.4 Policy and Innovation Unit Energy Review

The Policy and Innovation Unit (PIU) were asked to carry out a review of the strategic issues surrounding energy policy in the UK. One of its objectives was to inform the Government's response to the RCEP's 60% recommendation. The PIU use an extrapolatory approach to develop a 2020 business as usual scenario, but otherwise use the Foresight scenarios. A specific 60% reduction scenario is not developed.

The PIU use the Foresight Scenarios to provide carbon emission forecasts on a sector and scenario basis for 2020 and 2050. For the 2020 timescale shown in Figure 4.4 the PIU have also considered a Business as Usual scenario, which assumes existing government policy intervention but little other intervention up to 2020. The 2020 scenarios suggest that a low carbon future would be achieved in stages. The Global Sustainability and Local Stewardship scenarios achieve 38% and 45% reductions respectively.

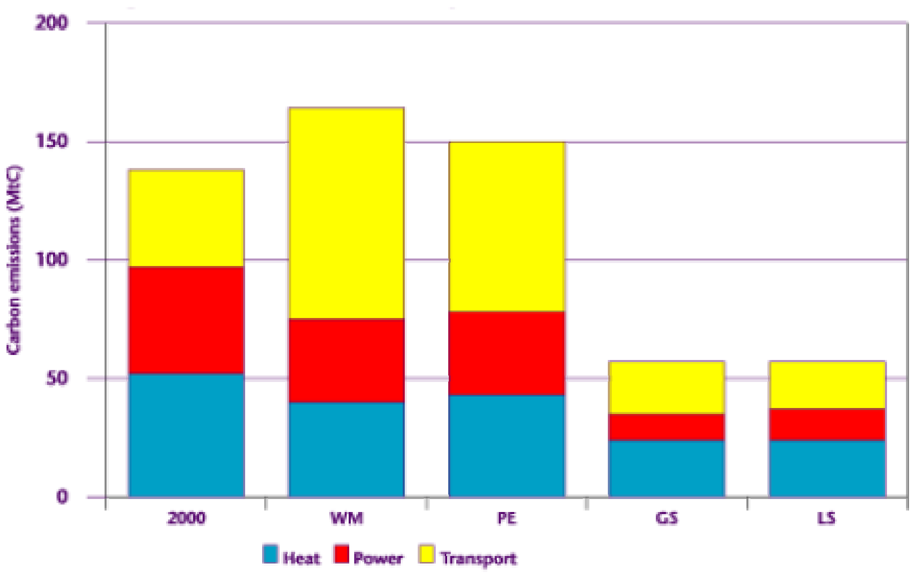
Figure 4.4 Carbon Emissions by Scenario by End Use in 2020 in the UK



Source: PIU, 2002

By 2050 the consumerist and individualist values of World Markets and Provincial Enterprise show emissions of 164 and 150 MtC respectively, with the transport sector providing a substantial contribution to emissions. The Global Sustainability and Local Stewardship scenarios in line with their conservationist and conservative values produce around 55MtC. This is shown below in Figure 4.5. Global Sustainability and Local Stewardship therefore achieve the 60% reduction. In order for this reduction to be achieved the PIU highlight certain requirements: large scale improvements in energy efficiency, the development of a low carbon electricity and low carbon transport systems, along with managed air transport growth.

Figure 4.5 Carbon Emissions by Scenario by End Use in 2050 in the UK



Source: PIU, 2002

The PIU recognises that increases in energy efficiency across all sectors could make a substantial contribution to the lowering of carbon emissions. For transport it suggests that energy efficiency improvements could contribute a 14 MtC reduction by 2020 and a 30 MtC reduction by 2050. Transport energy efficiency measures covered include the ACEA voluntary agreement (ACEA/EC, 1998), the use of hybrid engines and the potential use of fuel cells. However the PIU also suggests that in order to achieve the 60% reduction without large costs, new approaches will be needed in the transport fuel markets. In the longer term it envisages that hydrogen is the fuel most likely to replace oil, though oil is expected still to be the dominant fuel to 2020. It recognises that a hydrogen infrastructure would take time to develop, for the interim period it highlights the importance of softer transport measures including land use planning, improvements to public transport and encouragement of walking and cycling.

It is also worth noting that the two scenarios which achieve the 60% reduction: Global Sustainability and Local Stewardship, have a very much lower contribution of carbon emissions from transport than the other two scenarios, though power and heat are also reduced. The Foresight (1999b) work on the implication of these scenarios for transport also indicates alterations to travel demand. For example in the Foresight (1999b) Global Sustainability scenario, although road traffic continues to grow it is at a much slower rate than in the past. With Local Stewardship there is an emphasis on avoiding the need to travel, and car ownership and car use are reduced by the use of car-sharing, home deliveries and traffic management schemes.

The PIU also recognise that aviation is a major problem and suggest that the DTLR prioritise a discussion of taxes and other measures to manage aviation demand.

4.5 The Inter-departmental Analysts Group

The Inter-departmental Analysts Group (IAG, 2002) also details potential future carbon dioxide emissions for 2050. The IAG was set up to inform the Government's response to the RCEP's 60% recommendation and comprises officials from the Department of Trade and Industry, Department for Transport, Department for Environment Food and Rural Affairs, the Policy Innovation Unit and Her Majesty's Treasury.

The IAG use an extrapolatory method to determine several carbon projections for 2050. Two baseline projections are examined in detail, and the Foresight scenarios, used to indicate the range of potential future worlds. Carbon reductions are then applied to one of the baseline scenarios to illustrate how a 60% reduction could be achieved.

To determine the carbon projections the IAG use the Government's emissions projections, which are contained in Energy Paper 68 (EP68) up to 2010[5] (DTI, 2000). Since EP68 does not take account of the full range of measures incorporated in the subsequent UK Climate Change Programme, the IAG include a separate allowance. After 2010 the projections are based on various different assumptions regarding continued carbon intensity improvements, but also including the impact of closure of existing nuclear generation plant and constraints, which reflect limits on fuel switching potential.

[5] The IAG notes that the EP68 provides projections to 2020 and that it is equally possible to use them as the basis to 2020, with divergence allowed beyond that point. However they are not the IAG's preferred baseline because the Climate Change Programme is aimed at 2010 (or at least the Kyoto period 2008-2012), and because allowing divergence from 2010 is probably a better reflection of the uncertainties.

These different assumptions result in carbon projections for 2050 in the range of 103 – 167 MtC, and these are illustrated in Table 4.8. The second column shows carbon intensity change, which refers to the ratio of carbon emissions to GDP. The IAG examines two of the carbon projections in detail; these are Baseline A and B in Table 4.8. Baseline A consists of the historic (1970-2000) carbon intensity change, and includes nuclear closures, but does not include further dash for gas and fuel switching. Baseline B is the estimated EP68 (2000-2010) carbon intensity change, which includes the Climate Change Programme and nuclear closures, but like Baseline A does not include dash for gas (DFG) and fuel switching.

Table 4.8 Carbon Projections for 2050

Basis for Projection	% change in Carbon intensity per unit of GDP (post 2010/20)	Carbon projection (MtC) in 2050
Energy Paper 68 TO 2010 AND THEN:		
Historic (1970-2000) p.a. carbon intensity change	-3.0	103
Historic (1970-2000) p.a. carbon intensity change, less dash for gas in Electricity Supply Industry, less impact of fuel switching in final demand, including nuclear closures (Baseline A)	-2.1	145
EP68 (2000-2010) projected p.a. carbon intensity change (including fuel switching in Electricity Supply Industry, Climate Change Programme and nuclear closures) (Baseline B)	-2.8	110
EP68 (2000-2010) projected p.a. carbon intensity change (including fuel switching in Electricity Supply Industry, excluding Climate Change Programme, including nuclear closures)	-1.8	162
EP68 (2000-2020) projected p.a. carbon intensity change (less fuel switching in Electricity Supply Industry, excluding Climate Change Programme, including nuclear closures)	-1.7	167

Source: IAG, 2002

To deal with the uncertainties involved in projecting forward to 2050 the IAG use the Foresight Future scenarios, but with slightly different figures from the original work (Foresight, 1999a). Some of the assumptions from the Foresight work were found to be inconsistent with current Office of National Statistics (ONS) long-term population projections (IAG, 2002). There were also concerns about assumptions made for economic growth. The IAG use of the Foresight scenarios is shown in Table 4.9. The EP68 baseline refers to both Baseline A and B.

The IAG also use the scenarios in a different way. Key assumptions, such as GDP, population and household numbers are used as well as some basic assumptions, for example improvements in vehicles, but the IAG do not explicitly consider the different rates of technological change. Behavioural aspects such as the willingness and capacity to introduce environmental measures are purposefully excluded. It therefore differs from the PIU use of the scenarios. The IAG then combines the adapted Foresight scenarios with baseline A and B.

Table 4.9 IAG use of Foresight Scenarios

	EP68 Baseline	World Markets	Provincial Enterprise	Global Sustainability	Local Stewardship
UK GDP growth p.a.	2.25%	3.00%	1.75%	2.25%	1.25%
Population in 2050 (million)	65	66	64	63	62
Household size in 2050	2.17	2.00	2.40	2.20	2.60
Implied household growth in numbers p.a.	0.30%	0.54%	0.00%	0.18%	-0.27%

Source: IAG, 2002

The carbon emission projections for baseline A and B independently and in combination with the Foresight scenarios are shown in Table 4.10. Baseline B offers a lower gap to the 60% reduction target because of its inclusion of the Climate Change Programme measures.

Table 4.10 Emissions in 2050 MtC under baseline A and B and the Foresight scenarios

	Baseline A	Baseline B
Baseline emissions	145	110
World Markets	180	131
Global Sustainability	132	98
Provincial Enterprise	129	96
Local Stewardship	94	71

The World Markets figures shown in Table 4.10 tie in with the figures produced by the PIU shown in Figure 4.5; however the carbon emissions from the other scenarios are different. This could be attributed to the different use of the Foresight scenarios in the two studies. In its use of the Foresight scenarios the PIU included behavioural aspects and societal change. For the Global Sustainability and the Local Stewardship scenarios this involved people moving towards more environmentally sustainable lifestyles. The 60% reduction was achieved. With the IAG use of the Foresight scenarios these behavioural aspects were intentionally excluded, and neither Global Sustainability nor Local Stewardship achieve a 60% reduction.

The IAG then examine ways in which a 60% reduction could be achieved using Baseline A with 2050 emissions of 145 MtC, as an illustrative example. This baseline projection is then broken down on a sector basis, as shown in Table 4.11.

Table 4.11 Sector projections of total baseline CO_2 emission projections in 2050 (MtC)

	2000	2010	2050
Industry	40	33	19
Domestic	40	34	30
Services	23	19	27
Transport	39	39	59
Non-Sectoral	13	9	9
Total	155	133	145

Source: IAG, 2002

To achieve the 60% reduction, an estimated reduction of 83 MtC is necessary. The IAG suggests that a combination of the following could provide overall emission reductions of 60MtC:

- Full achievement of all identified additional energy efficiency potential in the domestic, service and industrial sectors
- The continued penetration of renewables to reach 40% of energy generation
- The additional carbon reduction achievable if all generation were carbon free by 2050

There is therefore a gap of 23 MtC between this figure and the required 83 MtC. The IAG (2002) suggest that this remaining 23 MtC would primarily be achieved from the transport sector.

The baseline scenario that the IAG uses includes transport sector measures from the Climate Change Programme. The 59 MtC in 2050 emissions projection for transport (shown in Table 4.9) assumes a continuation of past trends including increased efficiency but does not include measures such as increased fuel prices, technology improvements, the potential effects of road congestion or saturation of car ownership. An alternative approach applied by DEFRA (2001a) results in transport emissions of 39 MtC by 2050. This projection includes the increased impact of congestion, saturation of car ownership, no new road build beyond 2010, some fuel switching from gasoline to biodiesel, reductions in rail fares to encourage modal shift, and the limited introduction of fuel cells. This baseline projection provides one illustration as to how 20 MtC of the 23 MtC reduction could be met. IAG suggest that if technical developments could deliver a greater switch to low carbon fuels then emission reductions could potentially be achieved with less constraint on transport demand.

With regard to aviation, the IAG acknowledges that at present only emissions from domestic flights are included, but that if the UK were to be assigned a share of international emissions achieving a 60% reduction would be made more difficult. If projections of growth in UK international aviation were made on the same assumptions across scenarios and baseline as those made for domestic aviation an additional 14 MtC would be added to the baseline projection based on the historic rate of carbon intensity improvement. An additional 21 MtC would be placed on the baseline projection based on the carbon intensity improvement expected between 2000-2010.

The IAG also highlights that carbon dioxide, although it is the most significant, is only one of a number of greenhouse gases. It suggests that it makes sense to look at other greenhouse gases and consider which can be reduced most cost effectively, but acknowledges that in the UK the easiest reductions in non-CO_2 emissions have already been made.

4.6 AEA Technology and ICCEPT

AEA Technology and ICCEPT were commissioned by the DTI, DEFRA and the PIU to develop 'bottom up' estimates of carbon dioxide emissions for the UK in 2050, and identify technical possibilities for and costs of reducing these emissions.

Three potential futures for 2050 were examined: a Business as Usual scenario[6], a World Markets scenario and a Global Sustainability scenario. Data about each of the scenarios (primary energy prices, demands for energy services and emissions constraints) and information about technological assumptions (data on costs, and performance of different technologies) were input into an energy systems model – MARKAL.

The AEA Technology/ICCEPT study is slightly different from the earlier studies in that not all components of the energy system are considered, for example emissions from oil refineries are not included. For the year 2000 it is estimated that these additional emissions would be equivalent to 20 MtC (AEA Technology, 2002). Emissions (not including this 20 MtC) are 132 MtC in 2000 (AEA Technology, 2002). Therefore in the analysis below the AEA technology figures are provided, but to allow for an approximate comparison with the other studies they are factored up by 15%.

Initially, the model was used to assess how the UK's energy system would develop under each scenario, assuming no carbon constraint. The model was then run with three levels of carbon abatement factored in: a 45%, a 60% and a 70% reduction (2000 was taken as the base year). The model responded to the carbon reductions by choosing combinations of fuels and technologies that achieved the reductions at least cost, while still meeting energy demands. Improvements in energy efficiency were therefore considered, but means of demand restraint were not. Issues concerning energy security were also not included.

Key results from the use of the model are discussed below. Full descriptions of the inputs to and the outputs from the model runs are provided in the appendix of the AEA Technology and ICCEPT report (AEA Technology, 2002).

Results - no carbon abatement

Assuming no carbon abatement the model indicates that conventional technologies and fossil fuels would continue to provide the majority of the UK's energy supply in all three scenarios. Alternatives would be in use only in niche areas. One output from the model, Primary Energy Use is shown in Table 4.12. Here energy demand is lower than 2000 levels, and is highest in the World Markets Scenario and lowest in the Global Sustainability scenario. This reduction in demand is linked to projected improvements in energy efficiency. The study suggests that primary energy intensity could fall by between 2.6% and 3.0% per year, compared with the historical average of 1.8% per year over the last 30 years. However the policy measures and social changes needed to produce these improvements in efficiency were not considered.

[6] In the AEA Technology/ICCEPT report the Business as Usual scenario is also called a baseline scenario. The term business is usual is used here to avoid confusion with the term baseline projection.

Table 4.12 Primary Energy Use (PJ) in the UK for different scenarios

	2000	2050		
		Business as Usual	World Markets	Global Sustainability
Coal	1621	159	148	146
Oil Products	2289	1979	2267	1606
Natural gas	3568	4232	4792	3761
Nuclear	296	0	0	0
Biomass	21	129	370	362
Primary renewables	35	114	114	114
Total	7795	6499	7577	5875

Source: adapted from AEA Technology, 2002

The reduction in demand coupled with fuel switching results in carbon emissions falling in all three scenarios (Table 4.13).

Table 4.13 Carbon emissions by sector and scenario (non carbon constrained world) in the UK (numbers in brackets are 15% higher to account for effect of additional emissions)

		2050		
	2000	Business as Usual	World Markets	Global Sustainability
Domestic	39 (45)	26 (30)	31 (36)	25 (29)
Industry	35 (40)	22 (25)	20 (23)	18 (21)
Service	23 (26)	17 (20)	19 (22)	15 (17)
Transport	35 (40)	38 (44)	46 (53)	30 (35)
Total	132 (152)	103 (118)	117 (135)	88 (101)
Transport's contribution	27%	37%	39%	35%

Source: adapted from AEA Technology, 2002

In a non-carbon constrained world, transport's contribution to overall emissions is expected to increase (Table 4.13). This is because an increase in vehicle kilometres more than offsets any improvements in vehicle efficiency (Table 4.14 and 4.15). Vehicle kilometres for car, HGV, LGV and aviation and transport's contribution to overall emissions are highest in the World Markets scenario and lowest in the Global Sustainability scenario. Public transport (bus and rail) vehicle kilometres driven are highest in the Global Sustainability scenario. Though the model examines a range of vehicle technologies, the range for cars is detailed in Table 4.14, the model output suggests that the internal combustion engine would remain the main source of propulsion for vehicles, with petrol as the major fuel for cars (Table 4.14) and diesel as the major fuel in goods vehicles and buses (Table 4.15). There would be a small role for alternative fuelled vehicles, and electrification of the railway system would occur in all three scenarios.

Table 4.14 Car technology deployment (bvkm) in a non-carbon constrained UK

		2050		
Car technology	2000	Business as Usual	World Markets	Global Sustainability
Car-gasoline ICE	347	482	575	340
Car-diesel –CE	49	0	0	0
Car-gasoline hybrid	0	0	0	0
Car-CNG ICE	0	38	46	30
Car-methanol ICE	0	37	45	29
Car-hydrogen ICE	0	42	52	33
Car-gasoline FC	0	0	0	0
Car-CNG FC	0	0	0	0
Car-methanol FC	0	0	0	0
Car-ethanol FC	0	0	0	0
Car-hydrogen FC	0	0	0	0
Car-electric	0	0	0	0
Total	396	598	718	431

Source: adapted from AEA Technology, 2002

Table 4.15 Technology Deployment in non-car modes (bvkm) in a non carbon constrained UK

Vehicle Technology	Year			
	2000	2050		
		Business as Usual	World Markets	Global Sustainability
HGV - diesel ICE	33	-	-	-
HGV - diesel hybrid		68	81	61
HGV – hydrogen ICE		-	-	-
Total HGV	33	68	81	61
LGV – gasoline ICE	12	-	-	-
LGV – diesel ICE	35	119	143	107
LGV – methanol ICE		-	-	-
LGV – hydrogen ICE		-	-	-
LGV – ethanol FC		-	-	-
Total LGV	47	119	143	107
Bus – diesel ICE	5	7	7	-
Bus – diesel hybrid		-	-	15
Bus – hydrogen FC		-	-	-
Bus – electric		2	2	4
Total Bus	5	9	9	19
Rail – passenger electric	1	2	2	5
Rail – passenger diesel	1	-	-	-
Total Rail	2	2	2	5
Air – Kerosene	1	2	3	1
Air – Hydrogen		-	-	-
Total Air	1	2	3	1

Source: adapted from AEA Technology, 2002

Carbon constrained world

After providing information about a non-carbon constrained world, the Markal model was used to detail how emission reductions would be achieved in a carbon-constrained world. Emission reductions were achieved through further improvements in efficiency and fuel switching. The further improvements in efficiency lead to reductions in the need for energy; this is shown by comparing Primary Energy Use in a non-carbon constrained world as seen in Table 4.12 with Primary Energy Use in a carbon constrained world illustrated by Table 4.16. For fuel switching, there is a dramatic move away from oil and natural gas becomes the major supplier of energy under all three scenarios at all three levels of carbon reduction. Nuclear, biomass and primary renewables also have a role to play.

Table 4.17 shows the resulting reduction in carbon emissions across the scenarios. In all cases transports contribution to the 45% target is less than proportionate, emissions fall by only 20 to 29% as other sectors make deep cuts. However, in order to achieve the more stringent targets significant reductions are required of the transport sector.

Table 4.16 Primary Energy Use (PJ) under a carbon constrained world given different emission reduction targets for 2050.

		Business as Usual			World Markets			Global Sustainability		
	2000	45%	60%	70%	45%	60%	70%	45%	60%	70%
Coal	1621	140	101	8	130	9	8	129	61	9
Oil Products	2289	1498	675	478	1226	650	321	1589	1060	490
Natural gas	3568	3050	3847	3764	3955	4834	4469	2857	2706	3510
Nuclear	296	519	528	765	623	738	973	337	497	569
Biomass	21	401	401	433	412	412	501	382	412	412
Primary renewables	35	356	353	300	361	33	417	353	411	355
Total	7795	5607	5575	5449	6345	6644	6271	5294	4736	4991

Source: adapted from AEA Technology, 2002

Table 4.17 Carbon emissions by sector and scenario in a carbon constrained world (numbers in brackets are 15% higher to account for effect of additional emissions)

		Business as Usual			World Markets			Global Sustainability		
	2000	45%	60%	70%	45%	60%	70%	45%	60%	70%
Domestic	39 (45)	19 (22)	18 (21)	12 (14)	23 (26)	17 (20)	13 (15)	21 (24)	18 (21)	14 (16)
Industry	35 (40)	15 (17)	12 (14)	9 (10)	14 (16)	9 (10)	8 (9)	14 (16)	10 (12)	8 (9)
Service	23 (26)	10 (12)	9 (10)	8 (9)	11 (13)	10 (12)	9 (10)	11 (13)	8 (9)	8 (9)
Transport	35 (40)	28 (32)	14 (16)	11 (13)	25 (29)	17 (20)	10 (12)	27 (31)	17 (20)	10 (12)
Total	132 (152)	72 (83)	53 (61)	40 (46)	73 (84)	53 (61)	40 (46)	73 (84)	53 (61)	40 (46)
Transport's contribution	27%	39%	26%	28%	34%	32%	25%	37%	32%	25%

Source: adapted from AEA Technology, 2002

The model output suggests that the car transport sector achieves these reductions predominantly through fuel switching to hydrogen and the use of fuel cell technology (Table 4.18), because the study concerns only technological options, car vehicle kilometres remain the same as a non-carbon constrained world.

Table 4.18 Car technology deployment (bvkm) in a carbon constrained UK

Technology	2000	2050								
		Baseline			World Markets			Global Sustainability		
		45%	60%	70%	45%	60%	70%	45%	60%	70%
Car-gasoline ICE	347	288	18	0	0	0	0	340	60	25
Car-diesel –CE	49	0	0	0	0	0	0	0	0	0
Car-gasoline hybrid	0	0	0	0	0	0	0	0	0	0
Car-CNG ICE	0	33	28	4	72	34	5	30	23	23
Car-methanol ICE	0	32	27	4	32	33	5	29	22	22
Car-hydrogen ICE	0	7	0	4	0	0	0	33	6	0
Car-gasoline FC	0	0	0	0	0	0	0	0	0	0
Car-CNG FC	0	0	0	0	0	0	0	0	0	0
Car-methanol FC	0	0	0	0	0	0	0	0	0	0
Car-ethanol FC	0	0	0	0	0	0	0	0	0	0
Car-hydrogen FC	0	238	525	586	614	651	708	0	320	361
Car-electric	0	0	0	0	0	0	0	0	0	0
Total	396	598	598	598	718	718	718	431	431	431

Source: adapted from AEA Technology, 2002

The hydrogen is assumed to come from natural gas with carbon dioxide capture and disposal. If carbon dioxide capture and disposal is not viable then it is assumed that hydrogen will be produced by gasification of biomass. It is assumed that hydrogen is introduced in a progressive manner and therefore deployment costs are minimised. The cost of pure hydrogen at transport refuelling stations is assumed to be £1.4/GJ. In recognition of the sensitivity of costs to the use of hydrogen the model was also rerun and it was shown that higher delivery costs (around £12/GJ) would result in the elimination of hydrogen. For cars methanol fuel cell vehicles were used instead.

Information about the introduction of fuel cell vehicles is not provided in the main report, an examination of the background data provided in the report's appendix suggests that the year for initial introduction of fuel cell vehicles is related to the scenario and abatement levels. Fuel cell vehicles are introduced earlier in a World Markets scenario, and under the 60 and 70% abatement reduction.

Interestingly, hybrid cars do not feature at all in the model output. Examination of the input data (AEA Technology, 2002) suggests that in 2000 this is due to high costs, and though these costs are predicted to fall by 2020 it is assumed that hydrogen fuel cell cars will be marginally cheaper than hybrid cars in 2020 and offer slightly lower total transport costs. Therefore the model 'favours' hydrogen fuel cell cars over hybrid cars.

Table 4.19 shows the model output for the other modes. It can be seen that changes relate to both the scenario and the level of abatement. For HGV's the options are diesel hybrids or hydrogen internal combustion engines. For LGV's the emphasis is on diesel internal combustion engines, though hydrogen and methanol fuel cells have a role to play under the World Markets 70% abatement scenario. Buses are powered by diesel hybrids and hydrogen fuel cells. As with the non-carbon constrained UK the railway system becomes electrified. Hydrogen powered aviation also makes a contribution under the World Markets 70% abatement scenario.

Table 4.19 Technology Deployment in non-car modes (bvkm) in a non carbon constrained UK

		Business as Usual			World Markets			Global Sustainability		
	2000	45%	60%	70%	45%	60%	70%	45%	60%	70%
HGV - diesel ICE	33	-	-	-	-	-	-	-	-	-
HGV – diesel hybrid	-	68	8	-	81	-	-	61	61	-
HGV – hydrogen ICE	-	-	60	68	-	81	81	-	-	61
Total HGV	33	68	68	68	81	81	81	61	61	61
LGV – gasoline ICE	12	-	-	-	-	-	-	-	-	-
LGV – diesel ICE	35	119	119	97	143	143	7	107	107	107
LGV – methanol ICE	-	-	-	14	-	-	18	-	-	-
LGV – hydrogen ICE	-	-	-	-	-	-	91	-	-	-
LGV – ethanol FC	-	-	-	8	-	-	28	-	-	-
Total LGV	47	119	119	119	143	143	144	107	107	107
Bus – diesel ICE	5	-	-	-	-	-	-	-	-	-
Bus – diesel hybrid	-	7	7	1	7	1	-	15	15	2
Bus-hydrogen FC	-	-	-	6	-	6	7	-	-	13
Bus – electric	-	2	2	2	2	2	2	4	4	4
Total Bus	5	9	9	9	9	9	9	19	19	19
Rail – passenger electric	1	2	2	2	2	2	2	5	5	5
Rail – passenger diesel	1	-	-	-	-	-	-	-	-	-
Total Rail	2	2	2	2	2	2	2	5	5	5
Air – Kerosene	1	2	2	2	3	3	2	1	1	1
Air – Hydrogen	-	-	-	-	-	-	1	-	-	-
Total Air	1	2	2	2	3	3	3	1	1	1

4.7 Comparison of studies

The following section provides an analysis of the five studies reviewed above, and is split into three parts. Firstly the methodology of the studies is examined. Secondly the different ways in which a 60% reduction could be achieved are identified. Thirdly the role of transport in achieving this 60% reduction is considered.

Table 4.20 Comparison of the methodology of the Five Studies

	RCEP	The Carbon Trust	PIU	IAG	AEA Technology/ ICCEPT
Scenario Approach	Prescriptive	Descriptive and Prescriptive	Prescriptive and Foresight	Descriptive and prescriptive	Descriptive and Prescriptive
Baseline Projection for 2050	Assumed that energy demand would remain at 1998 levels	2 baseline projections Approx 150 MtC and 120 MtC	No clear baseline projection but World markets scenario 165 MtC	5 baseline projections in the range 103 –167 MtC. 60% reduction only against 1 (145 MtC)	3 baseline projections 103, 117 and 88 MtC Excluding end use emissions (approx 20 MtC in 2000)
Number of Reduction Scenarios	4	2	2	1	3 for each baseline projection

As can be seen in Table 4.20 different scenario building approaches were used. The RCEP relied on the prescriptive approach working backwards from a 60% target. The IAG and the Carbon Trust used the descriptive approach with the baseline projections based on previous energy trends. To determine how targets would be met, the prescriptive approach was used. The PIU used a prescriptive approach for its 2020 business as usual scenario, but on a 2050 timescale used the more qualitative Foresight scenarios. The PIU, unlike the other studies, did not set out to develop a 60% reduction target; it instead used the Global Sustainability and Local Stewardship scenarios to suggest how a world which achieved a 60% reduction could develop. The AEA Technology and ICCEPT work used both a descriptive and prescriptive approach through the use of an energy systems model (MARKAL).

These different approaches mean that only the IAG, the Carbon Trust and AEA Technology/ICCEPT had clear baseline projections for the world in 2050. The IAG developed several baselines, but the 60% reduction target was set against only one. The Carbon Trust developed two baseline projections and two 60% reduction scenarios. The AEA Technology/ICCEPT work developed three baselines, and set three reduction scenarios against each baseline. The RCEP, because of its use of the prescriptive approach, had no such baselines, the starting assumption was that energy demand would remain at 1998 levels. Four scenarios were developed to achieve the 60% reduction. The PIU does not have a clear cut baseline projection; instead it uses a range of future worlds, though since the World Markets scenario is considered to be most like conventional development it is possible to consider this as a baseline projection.

Achievement of a 60% reduction in CO_2 emissions was obtained by the use of the following methods:

- Changes to Energy Supply
- Reductions in Energy Demand through:
    - Increased Efficiency
    - Energy Conservation

With regard to energy supply, the emphasis in the first four studies was on renewables. Other options included the use of fossil fuels with carbon sequestration and/or the use of nuclear power. With the AEA Technology/ICCEPT work the emphasis was on a move to increased use of natural gas. There was a small role for nuclear, biomass and renewables.

Reductions in Energy Demand relate to both 'energy conservation' which is the reduction in the consumption of energy and 'energy efficiency' which is the process of obtaining the same with lower use of energy (RCEP, 2000). The emphasis was on energy efficiency rather than energy conservation improvements. Efficiency improvements were achieved through the development and increased use of existing technologies such as Combined Heat and Power, and improvements across all sectors: Domestic, Service, Industrial and Transport. Detail about general energy conservation measures was limited, with the RCEP acknowledging that our culture encourages consumption and expenditure, not thrift. The need for energy conservation in the transport sector did receive recognition and this is discussed in the next section.

None of the studies included the potential role of carbon emissions trading, in which the UK could reach future targets by the purchase of tradable emission allowances from countries with carbon surpluses. These studies only considered CO_2 emissions and did not include other greenhouse gases. The IAG view was that the easiest reductions in non-CO_2 gases have been made.

Role of transport

The role transport was expected to play in achieving the 60% reduction varied amongst the studies. There were differences in both the magnitude of the expected role and the combination of the different measures used to achieve the reduction as can be seen in Table 4.21.

Energy supply

For transport, alteration to the energy supply means a move away from oil to a lower carbon fuel. The PIU suggests that a 60% cut in CO_2 emissions could only be met if fossil fuels were no longer the main means to supply energy to vehicles. The emphasis in the Energy Review (PIU, 2002) was on a move towards hydrogen as an energy carrier although it was recognised that biofuel may also play a limited role. Hydrogen was also mentioned by the RCEP, and the AEA Technology/ICCEPT work and was a significant contributor to the Carbon Trust's methods of achieving a 60% reduction.

Reductions in Energy Demand – Energy Efficiency measures

Efficiency measures suggested included increasing the fuel efficiency of current vehicles, the use of hybrids, and the reduction of road congestion to help reduce emissions produced by stop start movements. The future role of fuel cells received recognition in all of the studies.

Reductions in Energy Demand – Energy conservation measures

The AEA Technology/ ICCEPT work concerned only technological solutions, while energy conservation measures were effectively excluded from the Carbon Trust's baseline projection 1 60% reduction scenario and would have a limited role to play in the RCEP's Scenario 1. However they were important in the other three RCEP scenarios. Measures suggested included encouragement of modal switch and carpooling. IAG suggestions included no new road build beyond 2010, and reductions in rail fares to encourage modal switch. The Carbon Trust Baseline Projection 2 also suggests no new road build and modal switch. The Foresight report: Actions for Sustainable Transport (Foresight, 1999b), details energy conservation measures for the Local

Stewardship and the Global Sustainability scenarios. With Local Stewardship there was an emphasis on avoiding the need to travel, and local planning systems were in place that ensured that facilities would be available near people's homes. Global Sustainability suggested that by 2010 transport telematics would begin to substitute for mobility.

Aviation

None of the studies included emission contributions from the growing international aviation sector. At present Kyoto targets only include emissions from the domestic sector. However it is recognised that if international emissions were shared out, the UK would find it more difficult to reach a 60% target (IAG, 2002).

Synergies and Conflicts

The PIU (2002) suggest that road transport will remain dependent on oil for the next two decades, and this is likely to be offset by increased energy efficiency in road transport. This was considered to provide "a synergy with security objectives (no increased dependence on oil)" and "environmental objectives (no increase in greenhouse gas emissions; reduced vehicle noise)". The PIU also suggest that energy efficiency measures could increase the price of new vehicles. This could have an effect on demand, and therefore may increase the price of older vehicles used by poorer people. There are therefore potential social inclusion issues. There was little information in the other studies on possible conflicts and competition between or within sectors or how these might be resolved or avoided.

It is clear that for emission reductions from the transport sector the emphasis is on technological measures. This raises two issues for concern. Firstly, although technological improvements can bring about emissions reductions, recent improvements in efficiency have been offset by a range of factors including increased size of vehicles, and wider uptake of additional features such as air conditioning. These trends are likely to continue (Bristow, 1996, Fergusson, 2001). Secondly there is the possibility that the technology may not develop as quickly or as cost effectively as anticipated. This issue is recognised by the RAC Foundation (2002) which suggests that other options, which constrain the demand for vehicle use, need also be examined.

Table 4.21 Role of Transport in the Five Studies

Study	Transport Baseline Emissions	Reduction offered from transport sector	Methods used to achieve reduction
RCEP All scenarios	38.8 MtC	Energy demand stays at 1998 levels. Transport's role in achieving this stabilisation is not quantified.	Range including: congestion charging schemes, widening of VED bands and measures to ensure EU voluntary agreement achieved
Scenario 1	38.8 MtC	0 MtC	Increased efficiency of vehicles. Most cars would run on fuel cells
Scenario 2		9.7 MtC	Most cars would run on fuel cells. Land Use planning measures. Increased use of public transport
Scenario 3		9.7 MtC	
Scenario 4		14.0 MtC	No mention of additional measures
IAG	59 MtC	23 MtC	Range including: modal shift, limited use of fuel cells and saturation of car ownership
Carbon Trust Baseline 1	60 MtC	8.4 MtC	Fuel cell efficiency in transport
	60 MtC	14.96 MtC	Transport powered by hydrogen from renewables
Baseline 2	43 MtC	The 43 MtC is achieved through no new road build, reductions in car use, modal shift, fewer HGVs	
	43 MtC	6.82 MtC	Fuel cell efficiency in transport
	43 MtC	14.96 MtC	Transport powered by hydrogen from renewables
PIU	40 MtC (2000 figures) 85 MtC (World Markets)	20 MtC (to achieve GS and LS scenarios) 65 MtC (to achieve GS and LS scenarios)	PIU Energy efficiency measures. Use of fuel cells and hydrogen. Suggests energy efficiency could achieve a 30 MtC reduction. Foresight scenarios include demand reductions: transport telematics replacing mobility, and avoiding the need to travel.
AEA Technology /ICCEPT[1]	44 MtC Business as Usual 53 MtC World Markets 35 MtC Global Sustainability	12 MtC 45% reduction 28 MtC 60% reduction 31 MtC 70% reduction 24 MtC 45% reduction 33 MtC 60% reduction 41 MtC 70% reduction 4 MtC 45% reduction 15 MtC 60% reduction 23 MtC 70% reduction	Measures depend on scenario and level of abatement, and include: hydrogen fuel cell vehicles in cars, diesel hybrid and hydrogen internal combustion engine for HGVs, diesel hybrid and hydrogen fuel cell for buses, diesel internal combustion engines, methanol internal combustion engines and hydrogen fuel cells in LGVs, electrification of rail and hydrogen in the air sector under the 70% reduction World Markets scenario.

[1] The results provided by AEA technology/ICCEPT have been factored up by 15% as explained in section 4.6.

5 Transport Scenarios and Targets

In this chapter specific scenarios for the transport sector are developed drawing on the studies reviewed in Chapter 4. Two carbon dioxide emission targets for the UK are examined and the role of the transport sector in achieving these targets considered.

5.1 Targets and Baseline Scenarios

The carbon dioxide emission targets are determined using the RCEP interpretation of the contraction and convergence approach outlined in section 3.2. The RCEP provides information about four different stabilisation targets: 450 ppm, 550 ppm, 750 ppm, and 1000 ppm. Here we focus on the reductions needed for the 450 ppm and the 550 ppm targets. 450 ppm is considered a potential target in several papers (GCI 2002; Alcamo and Kreliemen 1996 and Azar and Rodhe 1997); this target allows for some scientific uncertainty and includes leeway for contributions from other, non-CO_2, greenhouse gases. 550 ppm is the most common stabilisation target (EC, 1996, RCEP, 2000). The recent energy White Paper (DTI, 2003) accepts the RCEP recommendation and takes a 60% reduction in emissions as a goal, based on stabilisation at 550 ppm.

A 450 ppm stabilisation target requires a 79% reduction in carbon dioxide emissions from 1997 levels by 2050. Since carbon dioxide emissions were 148 MtC in 1997 in the UK (DEFRA, 2002), stabilisation at 450 ppm means UK carbon dioxide emissions would need to fall to 31.1 MtC per annum in 2050. A 550 ppm stabilisation target requires a 58% reduction in carbon dioxide emissions from 1997 levels by 2050. To achieve stabilisation at 550 ppm, UK emissions would have to fall to 62.2 MtC per annum in 2050. These targets are shown in Table 5.1. Although the 58% reduction is referred to as a 60% reduction by the RCEP and in other work, the 58% figure is used in this chapter to ensure accuracy.

Table 5.1 UK Carbon Dioxide Emission Targets

Target ppm	UK emissions in 2050 (MtC)
450	31.1
550	62.2

Source: adapted from RCEP, 2000

To put the two emission targets of 31.1 MtC and 62.2 MtC into context, the studies analysed in Chapter 4 were used. Baseline projections of emissions for the UK in 2050 are shown in Table 5.2. The RCEP study did not provide a baseline projection. It assumed that energy demand in 2050 is fixed at 1998 levels for its scenario 1 and falls from 1998 levels for the other scenarios. This stabilisation of energy demand would be a reversal of trend. For the purposes of this project we assume that this stabilisation at 1998 levels acts as a baseline projection and that demand for energy results in the same level of emissions that were produced in 1998. This results in a 148 MtC baseline projection.

The studies also detail how emission reductions could be achieved. For reductions the RCEP uses four different scenarios to indicate how a 60% reduction in emissions could be achieved. We apply this 60% to the 148 MtC baseline projection. This results in total emissions of 59 MtC. This and the reductions offered by the other studies are included in Table 5.2. These figures correspond reasonably well with our emission targets of 31.1 MtC and 62.2 MtC.

Table 5.2 Baseline Projections for a 2050 world indicating transport's contribution before and after emission reductions

	Baseline Projections in 2050 (MtC)	Total Emissions in 2050 after reductions (MtC)
The Carbon Trust	Baseline Projection 1 = 150 Baseline Projection 2 = 120	Baseline Projection 1 = 42 Baseline Projection 2 = 37
The PIU [1]	World Markets = 164 Provincial Enterprise = 150	Global Sustainability = 55 Local Stewardship = 55
The IAG	Range of projections: 103, 145, 110, 162, 167. Uses 145 for further analysis	62
The RCEP	148	59
AEA Technology /ICCEPT [2]	Business as usual – 116 World Markets – 132 Global Sustainability – 99	45% reduction – 81 MtC 60% reduction – 60 MtC 70% reduction – 45 MtC

[1] This is our interpretation of the PIU work.
[2] The AEA Technology/ICCEPT work does not take into account end user emissions. These are factored up emissions as detailed in section 4.6.

5.2 Role of Transport

The role of transport in achieving the carbon dioxide reduction target was then considered. Two different options were developed. Method 1 assumes that transport's emissions, as a proportion of the total contribution would remain at 1997 levels. Method 2 allows transport's contribution to total carbon dioxide emissions levels to increase in line with forecasts.

Method 1: Transport's contribution fixed at 1997 levels
In 1997 the end use of transport produced 39 MtC of the total 148 MtC from carbon dioxide emissions, a 26.4 % contribution. Applying the 26.4% to the 31.1 and the 62.2 MtC results in transport contributing 8.2 MtC and 16.4 MtC.

Method 2: Transports contribution derived from forecasts
The second approach looks at the implications of existing forecasts for transport emissions. To determine the potential future contribution from transport, four of the five studies analysed in Chapter 4 were used. The RCEP work was not included, since the role of transport in achieving stabilisation of demand at 1998 levels is not quantified, and therefore large assumptions would have to be made. The results from the analysis are detailed in Table 5.4. This indicates that in a non-carbon constrained world, transport's future contribution to emissions would be expected to increase from present levels. Transport's contribution in 2050 is approximately 56 MtC or 41%. In a carbon constrained world there is a wide range of predictions for transport's contribution: the Carbon Trust and the IAG suggest that transport's contribution could increase further, with an average 67% contribution, while the AEA Technology/ICCEPT work suggests a different role, with transport's contribution being around 37% or 26%.

To determine transport's future contribution for use in this project it was decided to use the average contribution from transport emissions in a carbon constrained world. The AEA Technology/ICCEPT 45% reduction in carbon emissions was excluded from the calculation, since higher reductions are being examined. This results in a 41.3% contribution from the transport sector. Applying this to the 31.1 MtC and the 62.2 MtC results in emissions of 12.8 MtC and 25.7 MtC.

Table 5.3 Transport's contribution derived from forecasts

Study	Baseline Projection in 2050 (MtC)	Transports Contribution to Baseline Projection	Total emissions in 2050 after carbon reduction	Transport's contribution in 2050 after emission reductions
The Carbon Trust - Baseline Projection 1	150	60 (41%)	42.40	36.64 MtC (86%)*
The Carbon Trust - Baseline Projection 2	120	43 (36%)	37.26	21.22 MtC (57%)*
The PIU	World Markets = 164 Provincial Enterprise = 150	World Markets = 89 (54%) Provincial enterprise = 70 (47%)	Global Sustainability = 55 Local Stewardship = 55	Local Stewardship = 22 (40%)* Global sustainability = 25 (45%)*
The IAG	Range of projections: 103, 145, 110,162, 167 (145 used)	59 (41%)	62	36 (58%)*
AEA Technology	Business as Usual = 116	43 (37%)	45% reduction = 81 60% reduction = 60 70% reduction = 45	32 (39%) 16 (26%)* 12 (28%)*
	World Markets = 131	52 (39%)	45% reduction = 82 60% reduction = 59 70% reduction = 45	28 (34%) 19 (32%)* 11 (25%)*
	Global Sustainability = 99	34 (34%)	45% reduction = 83 60% reduction = 59 70% reduction = 45	31 (37%) 19 (32%)* 11 (25%)*
Transport's contribution	Average of those marked (*): 41.27 %			

5.3 Transport Targets

Table 5.4 shows the derived emissions targets for the transport sector.

Table 5.4 Transport Target Emissions

Total Emissions in 2050	31.1 MtC	62.2 MtC
Transport target emissions in 2050		
Method 1 (26.35% contribution)	8.2	16.4
Method 2 (41.27% contribution)	12.8	25.7
Reduction from Transport's 1997 emissions (39 MtC)		
Method 1 (26.35% contribution)	30.8	22.6
Method 2 (41.27% contribution)	26.2	13.4

It can be seen that when transport's contribution to emissions is allowed to increase in line with forecasts (method 2) the reduction required from 1997 levels is lower than when transport's contribution is expected to stabilise (method 1). Method 2 is based on forecasts of the effects of future policies and is therefore potentially a better representation of the future than method 1.

6 Conclusions

The objective of this report was to establish CO_2 emission targets for the UK transport sector in 2050. A literature review suggested two stabilisation targets for CO_2 of 550 ppm and 450 ppm. For the UK this implies total emissions in 2050 of 62.2 and 31.1 MtC respectively. Work then moved on to a review of five key studies containing future scenarios for CO_2 emissions for the UK. These studies were used firstly to establish feasible 2050 baseline projections for the UK and secondly to examine possible ways in which reductions could be achieved.

Two approaches were used to estimate the contribution of transport to total emissions in 2050:

- stabilisation at the current level of 26%
- an increase to 41 % derived from the studies reviewed

These percentage contributions were then applied to the 62.2 and 31.1 MtC emission targets and the emission reductions needed from transport's 1997 levels calculated. The results gave a range of reductions from 13.4 MtC to 30.8 MtC and a range of targets from 8.2 MtC to 25.7 MtC. Even the weakest of these targets implies a significant reduction from current emission levels.

The studies reviewed address changes in the transport sector at a very strategic level and in most cases assume a high degree of technological change. However, most recognise that changes in behaviour will also be required. The next stage in this study is to explore pathways by which these target reductions could be achieved at a much more disaggregate level for the personal transport sector.

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Glossary

MtC million tonnes carbon.

GtC gigatonnes of carbon (1 GtC =3.7 Gt Carbon dioxide)

PgC petagrams of carbon (1PgC = 1GtC)

ppb Parts per billion (10^9)

ppt Parts per trillion (10^{12})

PPM Parts per million the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air

PPM^V parts per million by volume

They are equivalent terms (Seakins P, 2002)

ICE Internal Combustion Engine

FC Fuel Cell

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