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LOW CARBON TRANSPORT FUTURES: HOW ACCEPTABLE ARE THEY?

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Abstract

Climate change is an internationally recognised problem. The transport sector in the UK is responsible for approximately 26% of the country's CO_2 emissions and this proportion is growing. If deep cuts in CO_2 emissions are required to slow the pace of climate change then the transport sector will have to play a role. This paper firstly examines the CO_2 reduction targets that might be applied to the transport sector and provides a justification for those targets. Secondly consideration is given to a range of different strategies that might enable the transport sector to achieve the targets. Finally the paper reports on results of a survey undertaken to explore the likely adaptation strategies of households in response to target reductions of 60% and examines the policies that are both likely to move society toward a low carbon transport future and are the most acceptable to households. The research reported in this paper are from a project funded by the Tyndall Centre for Climate Change Research exploring behavioural response and lifestyle change in moving to low carbon futures.

Keywords: Low carbon transport; Climate change
Topic Area: F3 Transport and the Environment: Energy Use, Greenhouse Gas Emissions and International Impacts

1. Introduction

Climate change is an internationally recognised problem. Carbon dioxide is the most important greenhouse gas and is projected to account for around 70% of radiative forcing of climate by the end of the century (IPCC, 2001a). The United Nations Framework Convention on Climate Change (UN FCCC) was agreed in 1992 and at Kyoto in 1997 developed countries agreed to targets which will reduce their overall emissions of six greenhouse gases 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). The 2003 Energy White Paper (DTI, 2003a) accepts the need for deeper cuts of 60% by 2050.

Transport has potentially an important role to play in achieving reduction targets. In the transport sector CO_2 accounts for 96% of greenhouse gas (GHG) emissions. The transport sector is the third largest source of carbon dioxide emissions in the UK and is the only sector where emissions are expected to be higher in 2020 than in 1990 (DETR, 2000a). Current UK transport policy aims to reduce emissions of GHG's from transport by 5.6 MtC below trend by 2010. This would leave emissions from the sector slightly above 2000 levels. This reduction is dependent on two key policies: the voluntary agreement between the European Commission 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 for transport (DETR, 2000b). In the longer run

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demand for motorised modes of transport is expected to increase and in the absence of further efficiency gains or developments in low carbon technologies for transport, emissions would then be expected to rise.

This paper reports results from a project funded by the Tyndall Centre for Climate Change Research exploring behavioural response and lifestyle change in moving to low carbon transport futures. The project had four key aims to:

- determine targets for CO_2 reduction in the UK transport sector and within this specifically for personal land based transport;
- develop strategies for personal land based transport to deliver these targets;
- explore the adaptation strategies of households in response to the strategies identified above; and
- identify policies that are both likely to move society toward a low carbon transport future and to be acceptable to households.

The paper addresses all of the project objectives and is structured as follows. In section 2 appropriate emissions reduction targets for the UK transport sector and specifically for the land based personal transport sector are derived. Section 3 examines measures that might contribute to reducing emissions from transport and considers combinations of measures that might deliver a 60% cut in emissions. Section 4 describes the development of a computer based survey tool designed to enable households to see the effect on emissions of changes in their travel behaviour. This tool is then applied in an experimental survey to explore the strategies households adopt when challenged to reduce their emissions from transport by 60%. Conclusions are drawn and policy recommendations made in section 5.

2. Derivation of targets

In this section firstly the degree of consensus on appropriate stabilisation levels for GHGs by 2050 is examined. Secondly the likely role of transport emissions in 2050 is explored by reviewing a number of studies that have developed scenarios to 2050 for the UK for carbon constrained and non-carbon constrained futures. This evidence is then used to estimate suitable targets for the UK transport sector.

2.1. Overall targets for reductions in greenhouse gas emissions

In the absence of intervention, anthropogenic GHG emissions will continue to increase (IPCC, 2001b) hence to achieve stabilisation emissions must be reduced. The current atmospheric concentration of CO_2 is about 371 ppm (DEFRA, 2003). A stabilisation target of around 550 ppm has come to be seen as an upper bound (RCEP, 2000; DEFRA, 2003). Climate models suggest that even if stabilisation at this level were to be achieved global temperatures could still rise by around 2^oC by 2100, leading others to support stabilisation at 450 ppm or even lower (Global Commons Institute, 2002; Alcamo and Kreilemen, 1996; Azar and Rohde, 1997). It is worthy of note that the IPCC (2001c) indicate that emissions must start to fall within 20 years for stabilisation at 450 ppm to be achievable.

The stabilisation targets refer only to CO_2. If other greenhouse gases are included then the "safe target" for CO_2 alone would be below 550 ppm. Therefore in this study it seemed appropriate to use both the 550 ppm and the 450 ppm stabilisation levels in developing targets for the transport sector. Other important issues to be decided include the assumptions made on the role of different countries in meeting targets and the timescale over which they should be achieved.

One proposed approach is Contraction and Convergence which aims to distribute emission reductions between countries on an equitable basis. It is a two stage process:

firstly convergence, that is the emissions levels of the developing nations would rise, and emissions levels of developed countries would fall until an agreed convergence point was reached. At this point all countries would have the same per capita emissions. Secondly contraction where all countries would reduce their emissions levels to a sustainable level. International negotiations would determine the upper limit of the concentration of GHGs, and the date when convergence would occur.

The RCEP used the contraction and convergence approach to estimate the reductions that would be necessary for the UK. They estimate that emissions would have to fall by 60% from 1997 levels to stabilise CO_2 at 550 ppm by 2050 and by almost 80% from 1997 levels by 2100. In order to stabilise at 450 ppm a fall in emissions of 80% by 2050 would be required. The RCEP therefore recommended 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).

In this paper the RCEP targets of roughly 60% and 80% reductions for stabilisation of 450 and 550 ppm in 2050 are used. There are several reasons for this: firstly, stabilisation at 450 ppm and 550 ppm has the greatest support in the literature; secondly the Contraction and Convergence approach has substantial political and scientific backing; thirdly, since this work focuses on the UK, there is a need for appropriate UK targets and; fourthly the RCEP is a long established, influential body, and these target figures are already being used in policy work for the UK. An additional supporting argument is the recent UK Energy White Paper (DTI, 2003) which accepts the case for a 60% reduction in CO_2 emissions by 2050.

2.2. Review of future scenario studies

Five recent studies are reviewed here, each of which has utilised the RCEP recommendation of a 60% reduction target. Each provides an indication of the role that transport is expected to play. The studies acknowledge the difficulty in predicting future change in the transport sector and in developing measures that will impact upon current emissions trends. Naturally, given the need to forecast to 2050, the studies make a number of assumptions about future conditions. The five studies are:

- The RCEP (2000) Twenty Second Report: Energy the Changing Climate.
- The Carbon Trust (2001): Draft Strategic Framework[c].
- 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.
- AEA Technology (2002): 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.

All of the studies recognise the need for substantial change in order to achieve a 60% reduction in carbon dioxide emissions by 2050. The Carbon Trust (2001), the RCEP (2000), and the IAG (2002) 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. There are four scenarios: World Markets; Provincial Enterprise; Global Sustainability; and Local Stewardship. They are set within the context of two dimensions of change: social values and governance systems. There is no business as usual scenario but the World Markets scenario could be considered to most closely resemble conventional development.

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

Table 1 summarises the varied roles transport is expected to play by the five different studies to achieve a 60% reduction. This includes only those scenarios that yield a reduction in CO_2 emissions of 60% or more. In most scenarios there is a heavy emphasis on technological solutions to reduce emissions from individual vehicles through the use of fuel cells and hydrogen from low or no carbon sources. Nevertheless there is a great deal of variation in the total and proportionate share of emissions from the transport sector.

Table 1: Transport Scenarios to 2050

Study and baseline	Baseline transport emissions MtC and (% share)	Changes to transport demand and supply	Total Emissions 2050 MtC	Transport Emissions 2050 MtC (% share)
RCEP	38.8 (26%)	Scenario 1: efficient vehicles, switch to fuel cells Scenario 2 and 3: 25% reduction in transport energy demand through use of fuel cells, increased public transport use, changing lifestyles, use of telecommunications. Scenario 4: 33% reduction in transport energy demand.	59	Scenarios 2 to 4 imply a slight increase in transport's share of emissions.
Carbon Trust Baseline 1	60 (41%)	Low carbon future, savings of 8.4MtC from fuel cell efficiency and 14.96MtC from sourcing H_2 from renewables	46.64	36.64 (78.6%)
Carbon Trust Baseline 2	43 (36%)	Low carbon future, savings of 6.82MtC from fuel cell efficiency and 14.96MtC from sourcing H_2 from renewables	37.26	21.22 (56.9%)
PIU no baseline		Global Sustainability and Local Stewardship both could reduce emissions by up to 30MtC through increased efficiency, land use changes, increased use of public transport and non-motorised modes	55	25 (45.4%) GS 22 (40.0%) LS
IAG	59 (41%)	Technology leading to the use of low carbon fuels, congestion grows, no new road building, saturation of car ownership and reduced rail fares.	62	36 (58.1%)
AEA BAU	43 (37%)	A 60% reduction involves 87.8% H_2 fuel cells A 70% reduction involves 98.0% H_2 fuel cells	60 45	16 (26.7%) 13 (28.9%)
AEA World Markets	52 (39%)	A 60% reduction involves 90.7% H_2 fuel cells A 70% reduction involves 98.6% H_2 fuel cells	59 45	20 (33.9%) 12 (26.7%
AEA Global Sustainability	34 (34%)	A 60% reduction involves 74.2% H_2 fuel cells A 70% reduction involves 83.8% H_2 fuel cells	59 45	20 (33.9%) 12 (26.7%)

The Carbon Trust and IAG are fairly pessimistic on the ability of the transport sector to deliver significant reductions in emissions relative to other sectors. The Carbon Trust (Baseline 1 low carbon future) has emissions from transport at a similar level to current emissions and comprising nearly four fifths of total emissions. They assume increasing efficiency and a massive shift to low and no carbon technologies in other sectors. At the other end of the scale are the AEA forecasts where the share of transport hardly changes. However, these were specifically designed to show how technology could be used to achieve emissions targets.

All five studies assume that some fuel switching will occur in transport. This is at its most extreme in the AEA Technology/ICCEPT study. In this case up to 98.6% of transport power is from hydrogen fuel cells. Efficiency measures included increasing fuel efficiency, use of hybrids, and the reduction of road congestion to help reduce emissions produced by stop start movements, although IAG also see congestion as a constraint on traffic growth.

All the studies (except AEA Technology/ICCEPT where the remit was to consider technological change alone) recognise the need for behavioural change. Examples include: no new road build (Carbon Trust and IAG) and increased use of public transport (RCEP, PIU and IAG).

These studies expect significant emission reductions from technological measures. However, recent improvements in efficiency have been offset by a range of factors including: increased mileage driven by economic growth and lower motoring costs, increased size and weight of vehicles, and wider uptake of additional features such as air conditioning (Fergusson, 2001). It is also possible that the technology may not develop as quickly or as cost effectively as anticipated (RAC Foundation, 2002).

2.3 Transport scenarios and targets derived

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.

The key question is what role should transport play in achieving the overall carbon dioxide reduction targets identified? In order to reflect the uncertainty of long term forecasts reviewed above two levels of contribution are derived: Option 1 assumes that transport's emissions remain at the same proportion of total emissions as in 1997. Option 2 allows transport's proportion of total carbon dioxide emissions levels to increase in line with the average of the studies reviewed.

Option 1: Transport's contribution fixed at 1997 levels. In 1997 the end use of transport produced 26.4% (39 MtC) of total CO_2 emissions (148 MtC). 26.4% of 31.1 MtC and 62.2 MtC overall emissions targets yield transport emissions of 8.2 MtC and 16.4 MtC respectively.

Option 2: Transports contribution derived from studies reviewed. The average contribution from transport to emissions in a carbon constrained world from four of the studies is used (it was not possible to derive a share from the RCEP study). This results in a higher contribution from the transport sector of 41.4%. This is in line with other UK research (DTI, 2003b) indicating that transport carbon savings are among the higher cost options, compared to other sectors, and hence it is to be expected that transport's carbon contribution may end up higher than it is now. This is also reflected in work for the EC (Blok et al, 2001) suggesting that the transport sector will play a limited role in meeting the Kyoto targets as reductions in other sectors are more cost effective. The 41.4% figure is also close to the estimates for a non-carbon constrained world and gives transport emissions of 12.9 MtC and 25.8 MtC. Table 2 shows the derived emissions targets for the transport sector.

Table 2. Transport Sector Target Carbon Emissions

	450 ppm stabilisation	550 ppm stabilisation
Total Emissions in 2050	31.1 MtC	62.2 MtC
Transport target emissions in 2050		
Option 1 (26.4% contribution)	8.2 MtC	16.4 MtC
Option 2 (41.4% contribution)	12.9 MtC	25.8 MtC
Reduction from Transport's 1997 emissions (39 MtC)		
Option 1 (26.4% contribution)	30.8 MtC	22.6 MtC
Option 2 (41.4% contribution)	26.1 MtC	13.2 MtC

Option 2 is based on forecasts and is therefore probably the better representation of the role of transport. However, the more stringent targets in Option 1 are also useful, given the risk that other sectors may not be able to deliver reductions in excess of the 60% and 80% targets to 2050.

2.4. Targets and forecasts for land based personal transport

National Road Traffic Forecasts (NRTF) suggests that personal land based transport's contribution to transport emissions (currently around 65%) is likely to fall to around 60% by 2050 (DETR, 1997). The estimated targets for transport as a whole and for personal land based transport, assuming a 60% share of transport emissions, are shown in Table 3.

Table 3. Target emissions from land based personal transport for the UK in 2050

	41.4% contribution	26.4% contribution
79% reduction (31.1 MtC)		
Total transport Personal land based transport	12.9 MtC 7.7 MtC	8.2 MtC 4.9 MtC
58% reduction (62.2 MtC)		
Total transport Personal land based transport	25.8MtC 15.5 MtC	16.4 MtC 9.8 MtC

To place these emission targets into context, potential carbon emissions in 2050, from the land based personal transport sector, were calculated. The initial assumption is that no improvements in car vehicle technology or changes in policy take place, giving what could be termed a worst case trend forecast. Current well to wheel emissions per kilometre were combined with predicted increases in car travel. Low, Central and High NRTF estimates were used with a continuation of trend assumed for the period 2031-2050 (DETR, 1997). Current car vehicle kilometres are approximately 380 billion. The forecasts to 2050 range from 494 billion kilometres under the low growth assumptions to 686 billion kilometres under a high growth assumption. This results in carbon emissions from cars increasing from approximately 21.5 MtC to 33.8 MtC under the central NRTF assumptions.

It was assumed that increases in efficiency would reduce carbon emissions from bus, rail and motorcycle operation and vehicle manufacture from approximately 5.5 MtC at present to 1.6 MtC in 2050. Although this is a strong assumption it was thought plausible due to increased electrification of rail and because it is easier to introduce new fuels and technologies in fleet based vehicles (buses). The total carbon emissions from personal land based transport under the trend scenario for NRTF central growth assumptions are shown in Table 4.

Table 4. Trend growth in total carbon emissions from personal land based transport under central growth forecasts (MtC)

	2001	2010	2020	2030	2040	2050
Emissions	27.0	30.2	31.6	32.9	34.2	35.4

3. Developing strategies to meet the targets

In order to examine how the targets in Table 3 might be achieved it was essential to gain a clear idea from the literature of the possible contribution of individual categories of measures, namely, technology, public transport, walking and cycling, restraint measures and land use. Most estimates in the literature on impacts are short or medium term. Implementation strategies for each measure have been developed, based on best evidence from literature and taking into account some constraints on acceptability. When looking at technology no attempt has been made to identify the policies that would be necessary to secure such change. When looking at other policy areas evidence has been considered on existing relationships to prices and service quality and attempts have been made to identify feasible strategies and changes in traffic levels that could be secured. Improvements to public transport occur only after 2015 given the current condition of the rail network. Road user charging is initially revenue neutral and in this case improvements to public transport occur only after revenue is generated which might contribute to them. The assumptions and estimates reported were further validated to a degree through consultation with experts in the field.

3.1 Technology

The studies reviewed placed a heavy emphasis on the role of technology in delivering reduced emissions through improved efficiency and alternative fuel sources, therefore this aspect was considered first. The main possibilities include: hybrid vehicles, fuel cell vehicles powered by hydrogen, and more efficient petrol vehicles.

Average well to wheel emissions per vehicle kilometre for the 2001 car fleet are 205.5 grams CO_2. Two scenarios were developed both of which assume full implementation of the ACEA/EC (1998) agreement to achieve average new vehicle emissions of 140g CO_2/km by 2008. Scenario A assumes no further significant change and gradual fleet turnover to give a 25% reduction in emissions by 2050. Scenario B assumes a combination of new technology, improvements to current technology and changes in purchasing behaviour toward more efficient vehicles to yield a 60% reduction in emissions by 2050. The estimated well to wheel carbon dioxide emissions per vehicle kilometre (tailpipe emissions are uplifted by 1.15) to 2050 are shown in Table 5.

Table 5 Well-to-wheel carbon dioxide emissions (g/km)

	2001	2010	2020	2030	2040	2050
Scenario A	205.5	176.4	171	165	160	154
Scenario B	205.5	176.4	146	120	100	82

The best performing vehicles in terms of well to wheel CO_2 emissions available in the UK include the new (2004) version of the hybrid Toyota Prius (119.6g/km) and smaller diesels such as the Citroen C3 and Renault Clio both at 126.5g/km. Clearly the 25% improvement of Scenario A is achievable with existing technology. Indeed Scenario A could be viewed as a feasible do-minimum. Scenario B requires substantial technological advance, investment and widespread adoption of new technology.

Figure 1 shows the pessimistic trend scenario alongside A and B. For each scenario low, central and high NRTF estimates are illustrated. The four target emissions levels derived above are shown and under scenario B the weakest target is met for the low and central growth forecasts.

Further technological gains may be possible, based on a switch to hydrogen propulsion by 2050, but considerable uncertainties remain. These include: the probable time scale for fuel cell vehicles to be marketable; the availability of carbon neutral hydrogen and the need for such hydrogen in other sectors where the savings in terms of displaced carbon are initially higher.

A 60% reduction in CO_2 emissions from technology is an optimistic scenario. It is clear that behavioural change will be needed as an essential part of any strategy to achieve a low carbon transport future. Such behavioural change could also facilitate early movement in the direction of the targets, which is crucially important in order to prevent the build up of GHGs in the atmosphere.

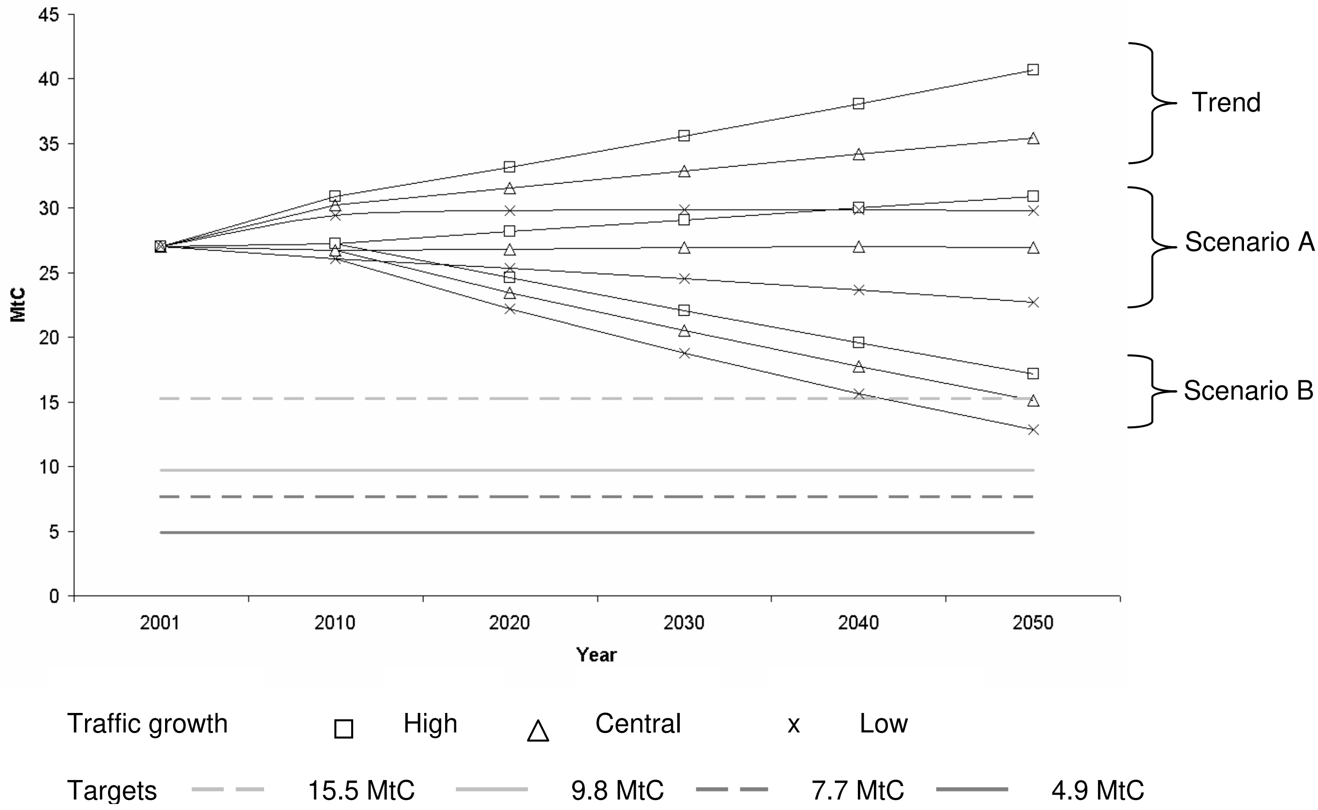

Figure 1. CO_2 Emissions Under the Trend, A and B Scenarios

3.2 Measures influencing behaviour

3.2.1 Pricing for road use

Two possible measures were considered (i) a national road user charge per vehicle kilometre and (ii) increases in fuel taxation. Increases in fuel taxation would not only reduce car use but also give an added incentive to purchasers to opt for a more efficient or alternatively fuelled vehicle.

National road user charging was assumed to be implemented in 2010 and was revenue neutral to 2015, offset by reductions in vehicle excise duty and fuel duty and was assumed to reduce vehicle kilometres by 5% in line with highest reduction estimate by the Commission for Integrated Transport (2002). Since this work was completed other commentators have questioned these results and suggested that total mileage might actually increase as, although the costs of motoring in urban areas will increase, costs will fall in rural areas (Foley and Fergusson, 2003). A short run elasticity of –0.16 was applied to 2020 and then a long run elasticity of –0.31 to 2050 (Brown et al, 1993). Figure 2 shows the carbon emissions produced when road user charging is combined with scenarios A and B under the three different levels of NRTF traffic growth. At this stage the impact on public transport of modal shift is not considered - effectively trips are either suppressed or switched to existing public transport services or non-motorised modes.

Fuel consumption is about twice as responsive to price change as traffic levels (Graham and Glaister, 2002). In this analysis only the impact on traffic levels is examined (elasticities of –0.15 in the short run and –0.3 in the long run) as some assumptions relating to technology have already been made, albeit without policy incentives to secure such changes. The impacts from a similar implementation and pricing strategy as for national road user charging would lead to a similar reduction in traffic levels.

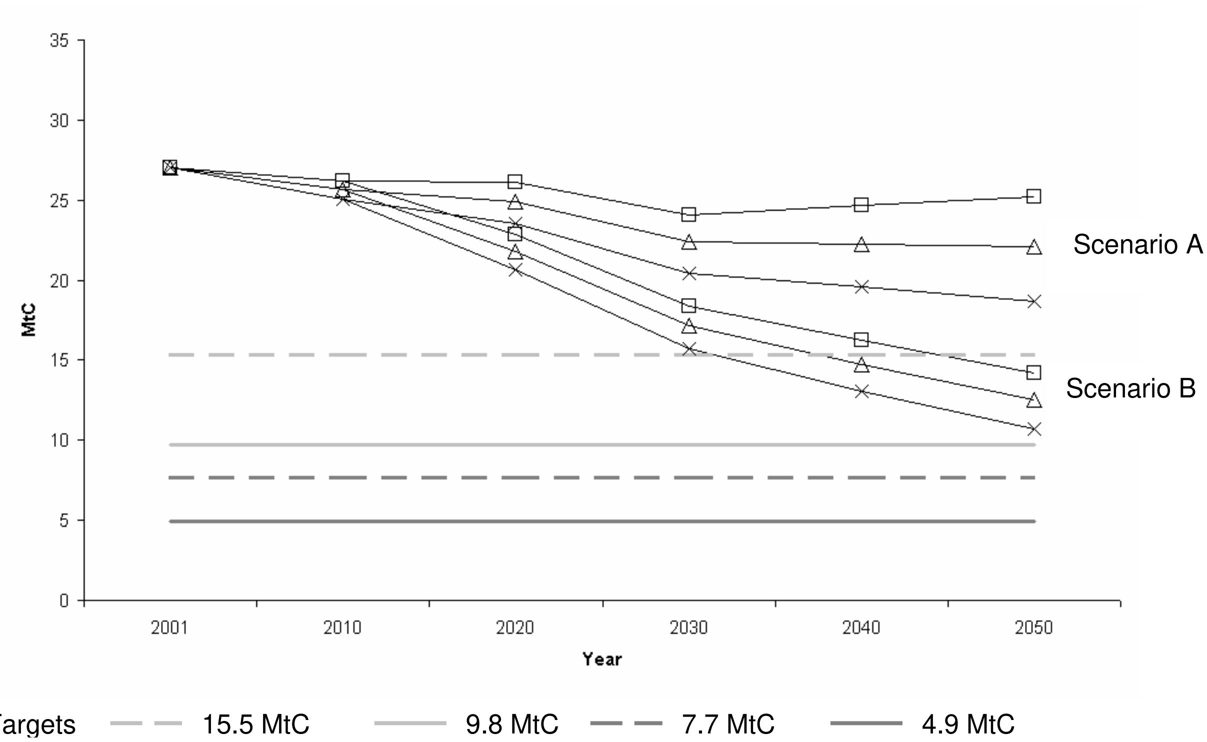

Figure 2 CO_2 Emissions Under Scenarios A and B with Road User Charging

Figure 2 shows, that the addition of a strong price signal in combination with the substantial technical advance of Scenario B reaches the weakest target under all the NRTF assumptions. However, none of the stronger targets are met.

3.2.2 Public transport

The key interest is in the diversion of trips from car to public transport. These cross elasticities are fairly low, especially with respect to bus. Those used here are for bus 0.002 (short run) and 0.0044 (long run) and for rail 0.0202 (short run) and 0.335 (long run); the derivation process is explained in Pridmore et al (2003).

Bus fares are assumed to fall by 3% per annum and service levels increase by 5% per annum between 2015 and 2035. Rail fares fall by 5% and service levels increase by 3% per annum between 2015 and 2035. After 2035 fares are held constant.

The 2030 emission reductions for public transport are partly offset by the provision of additional services. It is assumed by 2050 that the use of much lower emission buses and electrified trains powered by renewable energy remove this impact. The analysis suggests that improvements to public transport could lead to a small (8%) reduction in vehicle kilometres driven in 2050 reflecting the low cross elasticities. Rail provides 7% and bus 1% of this. Depending on the scenario and growth rate the additional reduction offered by improvements to public transport would be between 0.89 and 2.34 MtC by 2050. The weakest target is met by 2050 only under Scenario B with low and central NRTF growth. Compared with technology alone no new targets are met.

3.2.3 Telecommunications

The assumptions for 2050 are based on Salomon (1985), Van Ommeren et al (in Lake, 1997) and Handy and Moktarian (1996) such that by 2050 telecommunications replaces: 40% of business travel, 16% of commuting trips and 40% of shopping trips. Impacts on car and public transport were assumed to occur gradually. This outcome may be viewed as optimistic as it is assumed that all the car mileage is saved, whereas the car might be used by another household member or the telecommuter may use it for additional trips (Hopkinson et al, 2002).

Depending on the scenario and the traffic growth assumptions used, the additional emission reductions offered in 2050 vary between 1.95 MtC and 5.06 MtC. The weakest target is met by 2050 only under Scenario B for low, central and high NRTF growth.

3.2.4 Land use measures and improvements to walking and cycling facilities

Land use measures include: increasing development densities, the use of maximum parking standards and altering development patterns to encourage provision and use of public transport, and walking/cycling facilities (May and Matthews, 2001). To achieve significant traffic reduction, alterations to land use need to be integrated with transport policies (Paulley and Pedler, 2000). The DoE/DoT (1993) suggested that land use planning policies in combination with transport measures could reduce transport emissions by 16% over a 20 year period, while more recently WS Atkins (1999) considered that reductions in traffic of up to 2% could be achieved by 2010. It has been assumed that by 2050 land use measures alone could lead to traffic reductions of 10%. Depending on the scenario and NRTF rate used, reductions of between 1.60 and 4.20 MtC could be achieved in 2050. The weakest target is met by 2050 only under Scenario B for low, central and high NRTF growth.

3.3 Combinations of measures

In looking at combinations of single policy measures with technology the best appears to be pricing in delivering the greatest reduction by 2050. If applied using fuel prices, this would also incentivise drivers to move to efficient vehicles and to adopt new technology earlier. The next question is the degree to which each measure secures benefits additional to the others. It is clear that there is positive interaction between road and fuel pricing and additional measures. It is likely that some changes such as increased use of telecommunications will occur independently of transport policy. It seems justified to add the impacts of technology to those of fuel or road pricing as the estimates considered the effect of pricing on road traffic rather than on efficiency gains. However, if pricing is implemented then this will increase public transport use and this will reduce the impact of price and service changes on public transport, as there are now fewer car users to switch. Similarly pricing is likely to drive the take up of telecommunications and the development and use of walkable communities.

A single target 12.6 MtC by 2050 was considered which lies between the 15.5 MtC and 9.8 MtC targets and relates to a 58% reduction in carbon emissions by 2050 and a stabilisation target of 550 ppm. This reflects the target in the Energy White Paper (DTI, 2003). This allows the elaboration in some detail of three possible strategies that could deliver an emissions level of 12.6 MtC.

Strategy 1 involves dramatic technological change affecting the type of fuel and power mechanism used. There is no behavioural shift and car vehicle kilometres grow in line with central NRTF forecasts from 380 billion to around 600 billion. To reach the 12.6 MtC target, carbon emissions per vehicle kilometre would have to fall to 66 grams of CO_2 per kilometre. A car fleet mix of 42% hybrids and 58% powered by carbon neutral hydrogen fuel cells might achieve this. Hydrogen could be provided by electrolysis in which case a 39% increase in current electricity production would be required. If produced from woody biomass this would require approximately 36% of UK arable land.

Strategy 2 mixes technological change and measures to reduce demand. The average vehicle would emit 88.4 grams of CO_2 per vehicle kilometre. A car fleet mix of 68% hybrids and 32% powered by hydrogen fuel cells could achieve this. Under this strategy car vehicle kilometres grow from 384 to approximately 450 billion. However, this level is considerably below the central NRTF and will therefore require measures to reduce car use. Options include increasing the price of fuel by 2% a year from 2015 to 2050, an increase of 100% by 2050, or a nationwide road user charging scheme, revenue neutral from 2010 to 2015 and then increasing by 2% a year to 2050. The pricing measure would need to be accompanied by other measures to induce modal shift through bus and rail fares decreasing at 1% per annum and increased service provision at 1% per annum over the period 2015-2035. Additional methods of encouraging modal shift would include improvements to interchange, increased information provision, adherence to timetables and, for bus, increased priority.

Strategy 3 involves less technological change. CO_2 emissions per car vehicle kilometre would be 133.6 grams. This is achieved through improvement in fuel efficiency of internal combustion engines and use of hybrids. However, car vehicle kilometres would need to fall from current levels of 384 billion to 300 billion. To achieve this change options include increasing the price of fuel by 5.5% per annum from 2015 to 2050, an increase of 550% by 2050, or road user charging revenue neutral 2010 to 2015 and then increasing at 5.5% a year. Improvements in public transport on a similar scale to Strategy 2 would also be necessary. People would also be encouraged to live nearer their place of work, and telecommute. Walk and cycle facilities would be improved and there would be increased provision of local shops and facilities. The very large price increases under this strategy might well be expected to generate further gains in vehicle efficiency. Significant changes to attitudes and lifestyles would need to occur.

There are doubts about the ability of technology to deliver in terms of vehicle technology and securing carbon neutral sources of hydrogen. While it is possible that technology will deliver clean carbon neutral fuels for the future (RAC, 2002) the uncertainty is great. The High Level Group for Hydrogen and Fuel Cells (2003) do not see fuel cells becoming the dominant technology in transport before the 2040s in their "skeleton" proposal. Reliance on technology to deliver is risky due to uncertainty, possible offset of efficiency gains by increased demand and a need to secure reductions sooner rather than later if key stabilisation targets are to be achieved. The IPCC (2001c) indicate that in order to achieve stabilisation at 450 ppm world emissions must start to fall in the next 20 years.

It is clear that in the absence of significant technological advance, the implications for behavioural change and the policies to induce it are significant.

4. Household response

This section considers household response to the behavioural shifts required to meet reduction targets through survey work which explored household reactions to the need to reduce carbon emissions from transport by 60% and their adaptation behaviour. In order to address this issue a computer based survey tool was developed that had the ability to store and display trip details and the related carbon emissions for each household and to handle changes to trips estimating the resulting carbon emissions. Detailed travel diary information over a one week period was collected in order to estimate household emissions from travel.

4.1 Development and implementation of the computer based survey tool

The object of the tool is to allow a household to examine its emissions as a whole and as individuals and to experiment with different ways of reducing emissions and receive comparative feedback. In order to do this two key tasks needed to be performed: the storage and analysis of data and the visual display of data and changes in it in a way that respondents could understand.

The “base” is the starting point, the current travel patterns. Once this is input from the travel diary data, the interview can take place. The “base” is copied to the “default” and changes people make within their current context are recorded in the “default” while the base remains unchanged. A broad behavioural policy strategy is then examined whereby travel by other modes is facilitated and encouraged using the types of measure discussed in section 3. The interview focussed on behavioural change rather than technological change as any likely future outcome will require some adaptation and the survey is the only means of exploring this with people (any technological gains will to a degree be outside the control of the household). Finally an increase in vehicle efficiency is applied simulating a development in technology and all motorised vehicle emissions are reduced by 30% (a slight improvement on the earlier technology Scenario A, giving a slightly more optimistic view).

The software created works out emissions internally based on: distance, mode, vehicle type (car, taxi, motorcycle), driving cycle (car, taxi, motorcycle), shared journeys (car, taxi, motorcycle), train type (train), time of travel (bus) and marginal or average emissions (train, tube and bus). The results reported here are based on average emissions.

The interviews were conducted (after suitable piloting) during the summer of 2003. The survey was small scale and experimental designed to identify the usefulness of the approach as well as for the insights given into possible adaptation to low carbon travel behaviour. It was therefore decided to target a particular type of household, specifically those with higher than average car mileage as being the households with the scope to achieve significant reductions.

Once a household agreed to be interviewed they were sent an information pack containing a short survey on basic household information and types of vehicle owned, a travel diary for each member or the household, a consent form and a card for the households to keep in their car and record mileage.

Details of vehicles were required in order to allow the carbon emissions produced per vehicle kilometre to vary according to the characteristics of the vehicle. The travel diary recorded trips made by purpose, time, distance travelled (households were asked to estimate if unsure), and mode(s) used.

It was explained that the aim of the interview was to elicit opinions from households on how they would reduce their carbon emissions, under their current situation and future more ‘favourable’ situations. Households were first shown their own weekly emissions and two targets. Target 1 involved a straightforward 60% reduction in the household’s current transport emissions. Target 2 assumes UK carbon dioxide emissions from all sectors fall by 60%, but transport’s contribution to overall emissions increases from current levels to a mid-point between the 41.4% and 26.4% shares identified in section 3). It also assumes that emissions are equally allocated amongst the population and allows for some future population growth.

Detailed journey information for every household member for every day of the week was shown. The household was asked to consider how they would alter their travel behaviour under current circumstances in order to move towards the two targets. A sheet with carbon emissions per kilometre for different modes of transport was provided. The computer model was used to record the changes, and the households were prompted about barriers and advantages.

After the household had completed the emission reductions under their current circumstances the policy strategy was considered. Where under current circumstances they had mentioned an 'if' scenario e.g. "if there was less traffic, I would cycle", or "I would use the bus but it is not reliable or frequent enough" this was discussed. An attempt was made to quantify what improvements would be necessary e.g. how many buses per hour would you need to use the bus system in Leeds or what do you mean by reliable? A series of other possibilities were then introduced, including improvements in public transport, use of walking and cycling to replace short car trips, working from home, use of the internet, trip combining, car sharing and use of more fuel efficient cars.

Once the household had completed as many changes as they thought feasible, an improvement in technological efficiency was applied. This reduced all emissions by 30%. A discussion then took place which covered the following issues: why the household chose their current vehicle; how they felt about new technologies; how they felt about new fuels and; would they be willing to pay a price premium, and if so how much?

4.2 Results

Although only 15 households were interviewed, trip data exists for one week for 37 individuals, travelling a total of 12,602 kilometres. Household car travel ranged from 30 to 1350 kms for the week and all except two made walk trips. Eight households recorded bus travel, and four used each of cycle and taxi. Only two households recorded trips by train or motorcycle and one household made trips on the London underground.

Table 6 shows that a reduction of 10.59% in car kilometres was achieved under current conditions and bus use increased by over 150%, suggesting that changes are possible within the current system. The other mode to record very large percentage increases, albeit from a low base is cycle, where use doubled and then almost doubled again under a behavioural shift policy.

The reductions in car use achieved of 10.59% under current conditions and 19.21% under the behavioural policy strategy may be compared with other studies. The most obvious comparator is the work by Lee-Gosselin (1989) carried out in Canada and exploring household adaptation strategies to voluntary car restraint and rationing. In his study voluntary restraint reductions in fuel use per household amounted to around 16%. He concluded that the "threshold of pain" for voluntary savings was around 15%. Our results are remarkably consistent with those of Lee-Gosselin.

Table 6. Household kilometres by mode per week

Mode	Current	Changes made within current context	Changes made with facilitating policies
Car	8963	8014	7241
Walk	475	510	679
Bus	692	1520	1587
Train	1796	1170	1322
Taxi	193	154	135
Cycle	82	164	336
Motorcycle	375	386	351
Underground	26	26	26
Total	12602	11944	11677

Emissions per household for the current situation and the different strategies are reported in Table 7. Column 1 contains the household identifier and the two carbon reduction targets calculated for the household. The first is a straight 60% reduction in household emissions from transport. The second is derived from the targets identified earlier in this paper, allowing emissions from the sector overall to grow in terms of share, while the country as a whole reaches the 60% reduction target. The resulting transport emissions are then allocated equally between people. Emissions for households reaching target 1 are shown in bold and those reaching target 2 in bold italics, no households meet both targets.

Under current conditions a very small overall reduction in emissions is achieved. Although fewer car journeys are made, many of these journeys are switched to bus. Under current conditions the average emissions per bus passenger are not markedly better than those for car. This partly explains the small impact on emissions (3.10% for a 10.59% reduction in car use). Under the behavioural measures strategy most of the switching from car is to other modes including cycle and the resulting changes in emissions are greater, car use has now fallen by 19.21% and emissions by 13.34%. None of the households reach their targets under current or improved scenarios. Once efficiency and technological gains reduce emissions by 30% the targets become more achievable.

Table 7. Carbon emissions by household and scenario kilogrammes per week (percentage reduction in emissions from current in brackets)

Household and targets			Current emissions	Current context	Behavioural	Technology
1	9.28	7.25	23.19	23.14 (-0.22)	22.14 (-4.53)	15.50 (-33.16)
2	18.53	14.51	46.33	45.34 (-2.14)	40.35 (-12.91)	28.24 (-39.04)
3	11.58	14.51	28.95	27.33 (-5.60)	21.04 (-27.32)	14.73 (-49.12)
4	6.67	10.88	16.67	16.47 (-1.20)	14.02 (-15.90)	***9.81 (-41.15)***
5	6.80	3.63	17.00	16.25 (-4.41)	13.66 (-19.65)	9.56 (-43.76)
6	3.35	3.63	8.37	8.25 (-1.43)	8.25 (-1.43)	5.78 (-30.94)
7	12.35	7.25	30.87	28.48 (-7.74)	28.48 (-7.74)	19.94 (-35.41)
8	5.49	7.25	13.71	13.71 (0)	12.69 (-7.44)	8.88 (-35.23)
9	11.59	7.25	28.98	22.81 (-21.29)	22.81 (-21.29)	16.71 (-42.34)
10	15.67	14.51	39.18	39.18 (0)	33.73 (-13.91)	23.61 (-39.74)
11	5.07	3.63	12.67	12.67 (0)	6.69 (-47.20)	**4.68 (-63.06)**
12	3.84	3.63	9.61	9.61 (0)	9.61 (0)	6.73 (-29.97)
13	16.31	14.51	40.77	40.08 (-1.69)	35.70 (-12.44)	24.99 (-38.70)
14	12.24	14.51	30.59	30.33 (-0.85)	28.06 (-8.27)	19.64 (-35.80)
15	10.70	7.25	26.76	26.76 (0)	26.76 (0)	18.73 (-30.01)
Total	150.47	134.20	373.65	360.41 (-3.10)	323.99 (-13.34)	227.52 (-39.16)

Households who could envisage lifestyle change tended to favour the following modes and solutions (number of households in brackets): walk instead of car (3), cycle *if* there were less traffic (3), use public transport instead of car *if* reliable and cheaper (8), telecommute *if* employer would accept it (4), trip combining (1), use of households most fuel efficient car (2). There were also households for whom change in the current circumstances was not seen as possible due to the need to visit family members in remote areas, transport heavy items or to make leisure trips.

People did seem to be willing to try new power systems (for example hybrids and fuel cells) and new fuels (for example biofuels and hydrogen). While there was little enthusiasm to paying a price premium for a more environmentally friendly vehicle, if this also resulted in operating cost savings, the attraction grew.

No targets were met until technological change was introduced, when one household met both their targets and another met the second target. However, under a policy strategy favouring behavioural change, savings of 13.34% were achieved and with the addition of technological improvements in efficiency of around 30% this increases to 39.16%.

5. Conclusions and policy recommendations

5.1 Key findings

The UK economy will need to reduce CO_2 emissions by 60 to 80% in order to achieve stabilisation at 550 and 450 ppm respectively. A range of emissions targets have been derived for the personal land based transport sector from 4.9 MtC to 15.4 MtC depending on the assumptions made and the stabilisation level sought. Current emissions are 27 MtC. Future scenarios studies reviewed here place a heavy emphasis on technological solutions to the transport problem. A view recently reinforced by the Energy White Paper (DTI, 2003) which failed to mention behavioural shift. Even a 60% reduction in emissions per vehicle would only deliver the weakest of our targets with rising traffic levels.

Clear price signals to car users appear to be the most effective measure alongside technological change. The use of the price of conventional fuel as the instrument gives an additional incentive to switch to more efficient vehicles or to adopt new technologies earlier than would otherwise be the case. However it should be recognised that measures can "rebound" in a way that offsets direct benefits. For example improved fuel efficiency reduces cost of travel which then leads to an increase in the number of trips. Telecommunications facilitates home working but also a home location more distant from work and leisure or shopping trips may replace commuting trips.

Improvements to passenger transport, cycling and walking facilities, the siting of facilities closer to home and the increased use of telecommunications will also be required if change is to occur on a sufficient scale. Shifting trips from car to public transport may not secure significant reductions in CO_2 with the current vehicle fleet and load factors. A step change in emissions from passenger transport is required. An additional confounding feature of passenger transport is that improvements will attract trips from walk and cycle and generate new trips. This again reinforces the message that behavioural change beyond modal shift between motorised modes is required, including reductions in trip making and reduced lengths of journeys that will facilitate the use of non-motorised modes.

The survey suggests that even households which exhibit a willingness to change their behaviour would find it difficult, even under supportive scenarios, to achieve a 60% reduction in carbon emissions from transport. This suggests that a higher proportion than 30% of savings will have to come from technology. However, there is an ability to change, and this needs to be supported through improvements to existing provision and incentives to switch. The reductions in car use offered by households are in line with those found by Lee-Gosselin (1989).

The scenarios presented here have been constrained by political and social acceptability, hence the relatively late introduction of both pricing and improvements to public transport. Earlier intervention would be at a lower traffic level and thus measures could be gradual.

5.2 Policy

Clearly meeting the targets will require major changes over the coming years both in the nature of transport and in the way that transport is perceived and utilised by individuals and organisations alike. Developments in technology will go some way towards achieving the targets, but it is questionable whether this alone will be enough, especially if the wider international context of change is taken into account. Technology will achieve efficiency gains but these are likely to be offset by traffic growth (IPCC, 2001b, CfIT 2003).

An alternative to a complete reliance on technological change is to start to implement schemes aimed at changing transport behaviour. The scale of such changes is likely to be large and to require considerable lifestyle adaptation, though the advantage of such changes is that they could, at least theoretically, be implemented on a quicker timescale than technological change. Another advantage is the potential for synergy in introducing measures that may reduce other transport related externalities, particularly congestion (Proost, 2000). However, major barriers exist to implementing such developments in particular the need (still) to take the potential impacts of climate change seriously at both a political and individual level and for government to be willing to take a lead in promoting and enforcing a more sustainable transport future. The Energy White Paper (DTI, 2003a) only considered technological change with respect to transport and made no mention of behavioural change. The 10 year plan for transport (DETR, 2000b), even if fully implemented, will serve only to stabilise emissions from transport. There is considerable doubt as to whether many of the 10 year plan measures will be implemented within the time frame, especially the road user charging and work place parking levy schemes envisaged and the provision of sufficient rail capacity to carry the planned 50% increase in passenger miles (May et al, 2002). The Sustainable Development Commission (2003) estimate that the Government's 20% reduction target for CO_2 will not be met and consider savings from the 10 year plan "insecure".

Our work reinforces the message that technology alone cannot provide the answers. More rapid progress on measures to change behaviour is required. If we delay for a few years and then decide that behavioural shift is essential, the measures required become more extreme and hence more difficult to implement. Modal shift to public transport is a part of the solution, but emissions from public transport need to be addressed if significant reductions in CO_2 emissions are to be achieved. Pricing measures to restrain car use and encourage the take up of more efficient or alternatively fuelled vehicles are seen to be most effective in inducing behavioural shift. It appears that modal shift alone will not suffice and moves to reduce both the need and the desire to travel are required. A critical step will be in informing the public of the nature of the problem and the need to change and creating a desire to change, perhaps through the promotion of lifestyle change linked to improved quality of life.

There is a clear need for further research into long run behavioural shift and particularly in developing future "visions" within which households can envisage living. Existing knowledge is stronger on technology and pricing effects than on measures relating to telecommunications, service quality, walking, cycling and land use. Work is needed to establish responses to new or innovative combinations of measures.

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