Developing pathways to low carbon land based passenger transport in Great Britain by 2050

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Abstract

The key aim of this paper is to examine strategic pathways to low carbon personal transport in Britain and to compare these with the current trajectory of transport policy. A 2050 baseline was established using trend information, forecasts and best evidence from the literature on response to policy intervention. A range of strategies are tested including: technological development, pricing, public transport and soft measures. We conclude that even dramatic technological advance cannot meet the more stringent targets for carbon reduction in the absence of considerable behavioural change. The most promising combinations of measures involve clear price signals to encourage both a reduction in the use of motorised transport and the development and purchase of more efficient vehicles; decarbonisation of public transport and facilitating measures to enhance access whilst reducing the need for motorised travel.

Keywords: Climate change; Transport; Low carbon transport.

1. Introduction

The 2003 UK Energy White Paper (DTI, 2003a) accepted the need for deep cuts in CO_2 emissions of 60% by 2050 and such a reduction may become a binding commitment if the Draft Climate Change Bill becomes law (HM Government, 2007). As new evidence appears a 60% reduction looks increasingly inadequate; the UK Government's Chief Scientist Sir David King has stated that "we may have to increase that target perhaps to 80% by 2050" (House of Commons, 2005a). Some countries in Europe have already adopted more ambitious long term targets including Germany (80%), France (75%) and the Netherlands (80%) (Kawase *et al.,* 2006). Moreover, the Stern Review (Stern, 2006) has concluded that the costs of early action are outweighed by the benefits.

Nevertheless, greenhouse gas emissions in the EU (for the 15 countries committed to the Kyoto target of an 8% reduction overall) were only 0.9% below the 1990 base year levels in 2004, making it increasingly unlikely that the EU will meet its Kyoto Commitment without trading. In the transport sector CO_2 emissions have risen by 26% over the same period (European Environment Agency, 2006 and 2007). The UK has performed relatively well with overall CO_2 emissions in 2004 around 5.7% lower than in 1990 (HM Government, 2006) and is likely to meet its Kyoto commitments. However, emissions in the UK transport sector (including domestic air travel) were 10% higher in 2004 than in 1990 (HM Government, 2006).

The UK Government Climate Change Programme (CCP) (HM Government 2006) estimates that emissions from transport (as included in the Kyoto protocol) will be reduced from trend by 6.8 Million Tonnes Carbon (MtC) by 2010. The CCP savings are highly dependent on two key policies: the existing and planned future voluntary agreement between the European Commission and car manufacturers to bring down emissions of new vehicles to 135 g/km by 2020 and the Renewable Transport Fuel Obligation (RTFO)[1] aiming to achieve 5% renewables by 2010-11. In combination with supporting measures on Vehicle Excise Duty and Company Car Tax to encourage the purchase of lower carbon vehicles these measures are expected to deliver savings of 4 MtC by 2010[2]. Savings of 1.9 MtC (over a quarter of the total savings to 2010) are attributed to the Fuel Duty Escalator[3] (abandoned in 2000) indicating the effectiveness of an unambiguous price signal. A small contribution of 0.9 MtC is anticipated from "wider measures" (largely measures in the 10 year plan for transport (DETR, 2000) including a small number of examples of local road user charging schemes and workplace parking levy schemes[4], investment in public transport and other local plan initiatives and sustainable distribution). Revisions to these policies over time suggest that the saving by 2010 should be 7.3 MtC and 10 MtC by 2020. However, even if these savings are delivered in full they will only serve to stabilise transport emissions by offsetting trend increases and at best delivering a small absolute reduction. It is currently considered unlikely that the Voluntary Agreement or the RTFO will deliver their expected savings on time (CfIT, 2007).

It appears that UK transport policy is succeeding only in slowing the growth in CO_2 emissions from the sector. A limited number of studies have examined the scope for significant reductions in emissions from the transport sector, including Kwon (2005), Hickman and Banister (2007), Unweltbundesamt, 2000) and Åkerman and Höjer, 2006). All conclude that technology alone cannot deliver such cuts and significant behavioural change is required.

Here we seek to identify strategic pathways by which the personal land based transport sector might be able to deliver the deep cuts in carbon emissions of 60 to 80% by 2050 that would be required in order to achieve stabilisation of atmospheric CO_2 at acceptable levels. The focus is on personal land based travel as it is the largest source of transport emissions, 65% in 2001[5]. The paper looks forward to 2050 and is therefore necessarily speculative in nature, whilst drawing on state of the art evidence on trends, developments and behavioural response. The paper addresses the key gap between aspirations for long term reductions in CO_2 emissions and current government policies in the transport sector that clearly will not deliver such reductions.

Use is made of state of the art knowledge on behavioural response and causal relationships to examine future transport demand and supply. The approach was as follows:

- Derive specific targets for CO_2 reduction for the transport sector;
- Develop a spreadsheet model based on national aggregate data on vehicle kilometres by mode to establish a baseline;
- Apply the model to provide a do-nothing estimate of emissions in 2050;
- Explore a range of transport strategies that might achieve these targets, drawing on the literature and an expert Delphi consultation undertaken as part of this study;
- Combine strategies to meet targets;

The paper is structured as follows: section 2 outlines the derivation of CO_2 targets and baseline forecasts for the transport sector. Section 3 details the strategies examined both individually and in combination in seeking to meet the most stringent targets. Section 4 draws conclusions.

2. Deriving Targets and Baseline and Do-nothing Emissions

The UK Government has not set explicit targets for CO_2 reduction in the transport sector, nor had such targets been derived by others at the commencement of our study in 2001. Therefore, in order to derive targets for the transport sector it was first necessary to identify appropriate targets for the economy as whole for 2050 and then to examine the role of the transport sector in meeting those targets (see Tight et al (2005) for details).

Targets are normally discussed in the context of stabilising atmospheric concentrations of CO_2, which had reached 379 ppm by 2005 on a rising trend of 1.9 ppm per annum (IPCC, 2007). The most common targets are 550 ppm which is now seen as an upper bound (Royal Commission on Environmental Pollution, 2000) and 450 ppm, though there remains a degree of uncertainty with respect to avoiding dangerous climatic change. The Contraction and Convergence approach (Global Commons Institute, 2002) helps to identify the role of individual countries in moving towards global stabilisation through allocating emissions reductions between countries on an equitable basis. Essentially over time, emissions per capita in low emission countries increase, while those in high emitting countries decrease – *convergence* – once emissions are equalised all countries reduce emissions – *contraction*. The Royal Commission on Environmental Pollution (RCEP) applied this approach and estimated that the UK would have to reduce emissions from 1997 levels by 58% by 2050 to contribute to stabilisation at 550 ppm and by approximately 79% by 2050 to contribute to stabilisation at 450 ppm. These targets are adopted here because: they offer clear targets for the UK derived on an equitable basis; the approach has broad support including the endorsement of the Environmental Audit Committee of the British Parliament (House of Commons, 2005b); the RCEP commands respect; and the UK Government has accepted the case for a 60% reduction in emissions by 2050 (DTI, 2003). Total CO_2 emissions were 148 MtC in 1997 thus the targets for 2050 are 62.2 MtC (550 ppm) and 31.1 MtC (450 ppm).

The role of the transport sector in achieving such targets was examined through review of five national studies which utilised the RCEP recommendation of a 60% reduction target (Royal Commission on Environmental Pollution, 2000; The Carbon Trust, 2001; The Policy and Innovation Unit, 2002; The Interdepartmental Analysts Group, 2002; and AEA Technology, 2002). Most of these studies considered behavioural change, however, the bulk of emissions reductions in the transport sector were expected to arise from technological developments. There was a clear consensus across the studies that the historical trend which has seen transport emissions increase relative to those of other sectors would continue in a carbon constrained world. This is also in agreement with the DTI (2003b) findings that carbon savings in transport are high cost and more difficult to achieve compared to those in other sectors. The transport sector accounted for 26.4% of total emissions in 1997 - taking an average of the forecasts of the five studies suggested that this might increase to 41.4% by 2050 (Tight *et al.,* 2005).

In the absence of sector specific targets, the overall economy wide targets for reductions in CO_2 emissions of 60% and 80% are adopted here. Additionally, two scenarios on the transport sector's share of emissions are developed: firstly, that emissions increase to a share of around 41% reflecting the evidence from the national studies; and secondly, that the share of emissions remains as now. The second assumption is made to allow for the risk that other sectors are unable to deliver cuts in emissions in excess of the 60% or 80% that would be required and the possibility that new evidence on climate change may require even deeper overall cuts.

A spreadsheet model was developed for a baseline year of 2000 using data on vehicle kilometres from Transport Statistics GB (DfT, 2004a) and National Rail Trends (Strategic Rail Authority, 2005). The emissions factors for car, bus and motorcycle were obtained from the National Atmospheric Emissions Inventory (2005). These were then weighted according to kilometres run in urban, rural and motorway conditions and, where appropriate, for the proportion of diesel vehicles in the fleet. An aggregate emissions factor was applied for rail (DfT, 2004). The resulting emissions factors on an end user basis for 2000 are shown in Table 1.

Table 1 about here

The model produced a figure of 37.3 MtC for the transport sector in Great Britain in 2000. The DfT (2004a) reported emissions for 2000 (after netting out Northern Ireland emissions from the UK figure) is 38.9 MtC. This gives an acceptable difference of around 4% between our estimate and the recorded emissions, given our requirement for a relatively simple model in order to retain the flexibility to explore the effectiveness of a range of options to 2050. After removing freight transport emissions, the baseline CO_2 emissions for land passenger transport: car, bus, coach, motor cycle and passenger rail in 2000 is 24.8 MtC. The resulting target reductions are shown in Table 2.

Table 2 about here

The do-nothing baseline is based on actual data for car, bus and motorcycle for 2000 to 2003. Growth in car, bus and coach use was then assumed to follow the 1997 National Road Traffic Forecasts (NRTF) to 2031 for low, medium and high growth (DETR, 1997). These forecasts have performed reasonably over time. The original 1989 NRTF forecast a 25% increase in traffic from 1988 to 1996. Actual growth was 17%, the discrepancy being attributed to slower economic growth than assumed (DfT, 1997). The 1997 NRTF medium forecast growth was 19% between 1996 and 2006 whereas actual growth was 14.6% (DfT 2007), lying between the low and medium growth estimates. The NRTF forecasts include growth in the economy and population and assume static fuel prices after 2002 and a "broadly unchanged" road network (DETR, 1997). As pricing is a key policy area for investigation this simplifies the analysis considerably. After 2031 the trends are assumed to continue with slight dampening. The NRTF does not cover motorcycle and the long run trend for this mode is far from clear. The forecasts for this mode are based on the strong growth profile from 1993 to 2003 although it is perhaps arguable as to whether this will be sustained. However, in a capacity constrained transport system, strong growth in motorcycle use from what is still a low base is not improbable. The rail forecasts are based on actual changes in vehicle kilometres which show some growth from 2000 to 2004 (SRA, 2005), after that a slow rate of growth is applied reflecting the network constraints.

The emission factors in Table 1 were then applied to obtain carbon emissions by mode for each year between 2000 and 2050. Emissions factors for all modes are initially assumed to remain constant over the period to 2050. This provides a do-nothing or pessimistic baseline and is shown in Figure 1 alongside the targets. This is not an expected outcome but provides a transparent baseline against which to test policies.

Figure 1 about here

3. Developing strategies to meet the targets

In this section a broad range of measures that could be used to influence behaviour are examined to explore what could be achieved with respect to CO_2 reductions. These were:

- technological change and unrestrained demand;
- technological change and demand restraint through pricing;
- technological change and public transport service and fare levels;
- technological change, telecommunications and soft measures;
- pricing which drives both technological change and demand restraint;
- additional combinations of the above.

To aid comparability, the figures in this section all contain the do nothing baseline emissions as shown in Figure 1. The first year of implementation for all policies is 2005.

3.1 Technological change and unrestrained demand

The voluntary agreement between the European Commission and the European Association of Motor Manufacturers aims to achieve average new vehicle emissions for cars of 140g CO_2/km by 2008 in Europe. The UK figure for 2006 was 167.2g

(Society of Motor Manufacturers and Traders (SMMT), 2007), a reduction of 12.5% over an 11 year period from the 1995 base year. Clearly the target will not be met as the next two years would require a reduction of over 16%, a greater reduction than has been achieved over the life of the agreement. Yet SMMT (2007) estimate that if purchasers simply bought the best performing car in class (no need to switch to a smaller vehicle) new vehicle emissions could fall by over 30% to 116.2g/km. This would imply significant take up of hybrid cars such as the Honda Civic and Toyota Prius which according to SMMT are the lowest CO_2 emitters in the lower medium and upper medium classes. Customers in the UK are clearly opting for increased power, safety features (which often add weight) and air conditioning over efficiency (Zachariadis, 2006). It is clear that with no further advances in technology, reductions of 25 to 30% in vehicle emissions could be achieved if purchasing behaviour changed.

Clearly, over the period up to 2050 considerable additional savings might be expected through: further efficiency gains in internal combustion engines, hybridisation and changes in purchasing behaviour towards smaller and more efficient vehicles. It is conceivable that by 2050 almost complete decarbonisation of road transport could be achieved (up to 90% savings) through innovative vehicle and fuel technology developments and requiring decarbonisation of the power supply sector (King, 2008).. Whilst a switch to carbon neutral hydrogen could deliver additional gains many uncertainties remain including: the non-availability of carbon neutral hydrogen (Pridmore and Bristow, 2002), the need for substantial new electricity generating capacity (Kruger, 2005), the need for hydrogen in other sectors where the savings in terms of displaced carbon are initially higher (Eyre *et al.,* 2002) and whether hydrogen powered vehicles can enter the market and diffuse rapidly enough to take a substantial portion of the market before 2050 (High Level Group for Hydrogen and Fuel Cells, 2003; US National Academy of Sciences, 2004; European Commission, 2008). Another possibility is the use of biomass to create biofuels, however these have significant potential problems both in terms of social development, future sustainability and land requirements (House of Commons, 2008 and OECD/ITF, 2008) and are unlikely to enable us to meet more than a small part of the targets (even the King report only predicts a 5-10% reduction in carbon intensity of fuels over the next 10-15 years and does not go beyond this). Given current rates of progress towards existing technology targets such as the Voluntary Agreement, and the very long timeframes and risk associated with step change developments a 60% improvement has been assumed here. This would push the margins of known technologies, but would not necessarily require a leap forward to fuel cell technology.

The use of hybrid buses based on current technology could achieve savings in CO_2 emissions of 25 to 34%, with the largest savings in urban areas where stop start traffic and slow speeds prevail (Anable and Bristow, 2007). Sustainable biofuels (which might be more easily secured if confined to a relatively small sector like public transport) and battery operated vehicles (assuming the generation mix improves over time) could further enhance savings from buses, suggesting that a 60% reduction may be achievable.

Rail could be made more efficient through the electrification of the network, currently only 39% of the network is electric operation. Current performance indicates that CO_2 emissions from electric traction are 20% lower per vehicle kilometre than diesel traction (Atkins 2007). Electrification could then yield savings of around 12% for the rail sector, based on the current electricity mix and this would improve further over time. However, this would require considerable investment and locking in to one technology. Short term savings could be achieved through regenerative braking, energy metering and reducing the weight of trains and in the longer term hybrid trains (DfT 2007b) as with buses sustainable biofuels could have a role. The Rail Technical Strategy (DfT 2007b) envisages a next generation of inter-city trains that are 40% lighter per seat with, presumably, commensurate savings in energy. A 60% reduction in rail emissions through technology is very demanding.

In Figure 2 two technology scenarios involving a 25% and a 60% reduction in emissions per vehicle kilometre for all modes are presented. Whilst the pessimistic technology scenario is barely sufficient to offset the increase in emissions from traffic growth, the optimistic scenario would reach the weakest target given low growth in car traffic, from 393 billion vehicle kilometres in 2003 to 504 billion in 2050. A simplifying assumption has been made that the net effect of efficiency improvements is price neutral, thus there is no rebound effect. However, a rebound effect is expected as more efficient vehicles will use less fuel thus reducing the cost per kilometre and increasing demand. Recent UK Government analysis (DTI, 2007) incorporates a rebound effect using a price elasticity to mileage of -0.2[6], applying that to car use here would increase emissions by between 0.7 to 0.8 MtC in the 25% scenario and 1.8 to 2.3 MtC in the 60% scenario. These figures do not include the whole of the rebound effect as estimated by DTI (2007) which also included: increased use of in car equipment such as air conditioning, more aggressive driving and trading up to larger vehicles. It is therefore critical to have measures in place to "lock in" the full benefits of technological change.

Figure 2 about here.

3.2 Technological change and demand restraint through pricing

The simplest market mechanism, and that adopted here, is to directly restrain the use of carbon based fuels through taxation. Fuel prices were based on 2004 real prices (DTI, 2005 and ONS, 2005). The elasticity of demand for fuel use with respect to petrol price for car users is estimated to be around -0.25 in the short run and -0.77 in the long run (Graham and Glaister, 2004). This incorporates both the change in vehicle mileage and changes in purchasing behaviour or driving style to increase fuel efficiency. Increases in efficiency have already been allowed for in the technology scenarios, so whilst increases in fuel prices might be one of the drivers for that improvement, changes in prices are not expected to have an additional effect. For the purposes of this work we have made the artificial assumption that the price change impacts only on vehicle kilometres. The elasticity of vehicle kilometres to petrol price changes is -0.15 in the short run and -0.30 in the long run[7] (Graham and Glaister, 2002). The price increase will also assist to lock in gains by reducing any rebound effect from efficiency improvements.

Petrol price increases are expected to reduce motorcycle demand directly but indirectly increase demand as some car users, seeking more efficient vehicles, choose motorcycles. Given these potentially off-setting effects the impact on motorcycle use is assumed to be neutral.

Use of cars is approximately 12 times higher than that of public transport (Department for Transport, 2004c). Therefore, if even a small number of those who reduce their car use in response to the price increase switch to public transport, the need for enhanced supply could be substantial. Adopting both the diversion factors and the methodology for estimating cross price elasticity from Acutt and Dodgson (1996) produces cross-price elasticities with respect to bus of 0.0178 in the long run and for rail of 0.1500 in the long run. These cross elasticities are low, as expected, and similar to those produced by Acutt and Dodgson (1996) and Glaister and Graham (2005). An allowance has therefore been made for an increase in public transport vehicle kilometres over and above the assumed trend to accommodate those switching from car to bus and rail. The direct effect of the price increase on buses is assumed to be low as fuel is a small proportion of total costs and in Britain 80% of the tax is rebated as part of Government support to the bus industry.

After experimentation with a range of annual price increases, figure 3 is based on an annual price increase of 3.5% as under the optimistic technology scenario this delivers the 10 MtC target for the first time under the medium growth assumption*.*This outcome is dependent on the elasticities assumed. Recent modelling work for the Eddington Review (DfT 2006a) suggests that the price elasticity will fall over time as incomes rise and the value of time increases. If this occurs then higher price increases would be required to gain the same savings.

Figure 3 about here

3.3 Public transport pricing and provision

The technology scenarios assume that public transport delivers the same reductions in emissions per kilometre as cars. Here, the role of public transport in attracting trips from car is addressed. Price reductions and improvements to service levels would undoubtedly lead to increases in passenger kilometres but the bulk of this growth would come from existing users and those who transfer from highly sustainable forms of travel: walk and cycle. Cross elasticities of demand for car use with respect to changes in public transport prices and service levels were estimated, again using the method from Acutt and Dodgson (1996), and are even lower than the cross elasticities of demand for public transport use with respect to petrol prices. Car users are more likely to switch to rail than bus but even here the estimated cross elasticity is only 0.0144.

Nevertheless, annual improvements to bus and rail service levels and fare reductions of 2% per annum (5% for rail services to allow for the higher elasticity) were modelled over a 20 year period. The effects on car kilometres were trivial; a similar finding to Fowkes et al (1995) and Hensher (2007). Any savings in terms of car kilometres will be outweighed by increases in emissions from rail and bus services – largely to accommodate new journeys or those switching from more sustainable modes. Improving the public transport offer in isolation is not a sufficient "pull" measure. Nevertheless, improved service levels would be required to facilitate behavioural change resulting from "push" measures and this is clearly an area that would benefit from investment in lower carbon vehicles.

3.4 Soft measures / smarter choices

The definition of soft measures follows Cairns et al (2004) and includes: workplace travel plans, car sharing, teleworking, school travel plans, teleconferencing, on-line grocery shopping, local collection points, personalised travel planning, public transport information and marketing travel awareness campaigns and car clubs. There is a great deal of uncertainty as to the effectiveness of such measures in the longer run in large part due to a lack of a good evidence base.

The study by Cairns et al (2004) is a key summary of work in the UK context examining the potential of soft measures in the medium term. Given strong commitment and resources and appropriate changes in land use the authors conclude that car traffic levels could be reduced by up to 11% by 2015. Here an assumption is made that the maximum reduction in traffic levels achievable by 2050 from soft measures would be 25%. These reductions are applied to car traffic only. The use of other modes, such as walk, cycle and public transport is expected to increase as a result of certain of the soft measures such as travel plans and awareness campaigns. Preliminary findings from the UK Sustainable Travel Demonstration Towns (DfT, 2007c) suggest that concerted marketing campaigns can generate between an 11 and 13% reduction in car use, though this is in areas where public transport alternatives exist and where walking and cycling for some trips are genuine alternatives. However, even these highly focussed and well funded schemes do not seem to be able to exceed the potential suggested by Cairns et al (2004). Tight et al (2007) examined the potential for movement to lower carbon futures through behavioural change by households in the period to 2050 and conclude that there is a threshold value of around a 20% reduction in carbon emissions, beyond which it becomes very difficult for many households to contemplate further change as their lifestyles are so fundamentally linked to car use.

The impacts of soft measures when added to the technology scenarios are not as strong as those attained with the addition of pricing, allowing only the attainment of the weakest target under all traffic growth scenarios.

3.5 Policy Combinations

Thus far the technology gains have been assumed to happen. As one aim of this paper is to consider policies that would enable a move to low carbon transport, the change in technology needs to be incentivised. Therefore, the first step in moving to a set of measures is to allow increases in the price of petrol (again 3.5% per annum) to drive both the change in vehicle kilometres (as in figure 3) and the efficiency increase, again applying the elasticities produced by Graham and Glaister (2004) but this time allowing the whole effect. Thus instead of simply affecting miles driven the price of petrol is also assumed to influence the vehicle purchase – towards vehicles with lower levels of fuel consumption and hence emissions. Figure 4 indicates that this dual effect results in emissions that are slightly lower than those in figure 3. Emissions per new car are reduced to 56.72 g CO_2 / km. This goes further than the ambitious technology assumption of a 60% reduction in vehicle emissions from section 3.1 and is included to illustrate the difficulty of meeting the more stringent targets in the absence of a paradigm shift in transport technology. If price elasticities fall over time as suggested by work for the Eddington Review (DfT 2006a) and perhaps halved in the long run, then an annual price increase of around 7% would be required. This type of measure is unlikely to be politically acceptable.

Figure 4 about here

This combination achieves the 10 MtC target under low and medium growth scenarios and almost with high growth and achieves the 7.5 MtC under a low growth assumption. In order to achieve the 5 MtC target two additional policies are added:

- public transport becomes carbon neutral by 2050, although very ambitious this could conceivably be achieved by 2050 if research and development efforts were focused on fleet vehicles and any zero carbon energy available for transport were dedicated to these sectors, as their total energy use is relatively low, again this could be feasible;

- soft measures are implemented to facilitate behavioural change that occurs in response to the price signal. They are not assumed to induce any further behavioural change. This could be viewed as a conservative assumption.

The results are shown in Figure 5. It is clear that when working with conventional assumptions on behavioural relationships a combination of measures is required to drive changes in technology and behaviour. The measures in figure 5 achieve the 5 MtC target under the low growth scenario and imply a reduction in car kilometres of 35% from 2003 levels. The medium growth scenario is also close to the target with a lesser reduction in car use of 23%.

Figure 5 about here

5. Conclusions

This paper has explored ways of reaching stringent target reductions in CO_2 assuming that existing relationships between policy levers and behavioural response persist in the long run.

The weakest target, 15 MtC, represented a 60% reduction in CO_2 emissions over the economy as a whole, but allowed the share of the transport sector to increase. This is the only target that could theoretically be met solely through a 60% improvement in vehicle efficiency allowing growth in car kilometres of 28% by 2050. These estimates are probably optimistic given that the rebound effect would offset some of these savings in the absence of locking in measures and given that such a gain in vehicle efficiency is itself by no means certain, some additional behavioural change measures would be necessary even for this target. It is clear that only combinations of technological developments and behavioural change can deliver the deep cuts in carbon emissions which are required.

There is threefold range in the target levels, largely as a result of uncertainties over what share transport should take; this needs to be resolved through a policy debate. The more demanding targets require intensive action on both technology and demand.

In order to meet any such target it is clear that action is required now, if only because every year of traffic growth will make them more difficult to attain. Financial incentives are an effective mechanism for driving both technological change and behavioural shift, but must be supported by measures that facilitate reductions in the number of journeys, greater use of local facilities, access on foot or by cycle and low carbon public transport provision. This finding that combinations of measures are required to achieve long run cuts is consistent with the small number of studies that have examined the transport sector in depth.

This work is based on relatively simple assumptions. Areas identified for future research include: work to establish appropriate sectoral targets; exploration of the costs and benefits of different pathways; further development and understanding of the pathways to genuinely low carbon public transport; research on synergies between measures; improving access while reducing the need to travel – through localisation of provision and telecommunications; exploration of the sensitivity of results to underlying assumptions and an assessment of the transferability outside of the UK of the kinds of measures described in this paper.

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[1] The Government has recently consulted on ways of ensuring that bio-fuels are genuinely sustainable and deliver carbon emissions and is now consulting on reporting within the RTFO (DfT, 2007)

[2] The savings from the RTFO are 1.6 MtC, however, this is partly offset by increases in emissions overseas in the production of the biofuels.

[3] The Fuel Duty Escalator imposed an increase in fuel duty in addition to an inflationary increase, it ran from 1993 to 1999 by which time the annual additional increase was 6%.

[4] To date only two road user charging schemes have been implemented in London and a very small scale scheme in Durham and no work place parking levy schemes exist.

[5] Aviation is not included in this study due to the international dimension required to seriously address emissions from this sector.

[6] Small and van Dender (2007) estimate that the rebound effect has been falling in the USA to a level closer to -0.1 as a result of increasing incomes. However, they note that increasing fuel prices would serve to increase the effect.

[7] We have made a conservative assumption that short run elasticities prevail for some time as adjustments are made.

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Table 1: Emission factors by Mode Year 2000

Mode	Grammes Carbon per vehicle kilometre
Car	46
Motorcycle	36
Bus	302
Train	4336
LGV	76
HGV – articulated - rigid	288 152

Table 2 Targets for Carbon Emissions from Land Passenger Transport in 2050

Target	Transport: share of emissions as now 26.4%	Transport: share of emissions increases to 41.4%
60% reduction	10 MtC	15 MtC
80% reduction	5 MtC	7.5 MtC

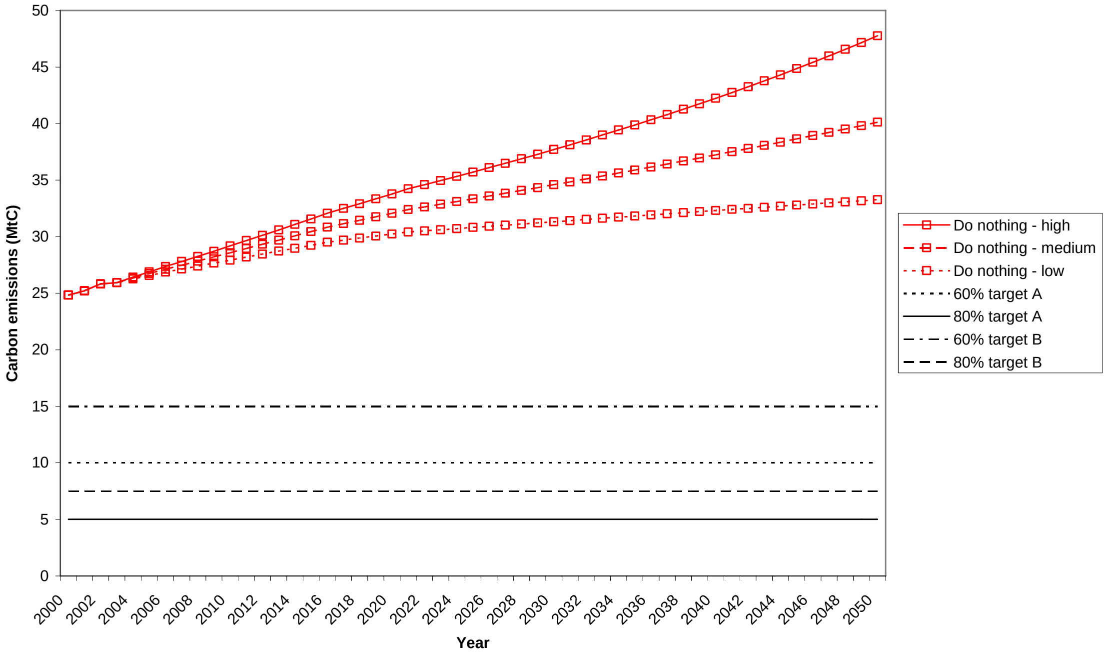
Figure 1: Do-nothing (baseline) carbon emissions and 2050 targets

Figure 2: Carbon emissions: do nothing, 25% and 60% technology scenarios

Figure 3: Carbon emissions: do nothing, 25% and 60% technology scenarios with 3.5% pricing

Figure 4: Carbon emissions: Price driving changes in technology and demand

Figure 5: Carbon emissions: Combined effects - most optimistic scenario



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Carbon emissions (MtC)
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2012
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2016
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2020
2022
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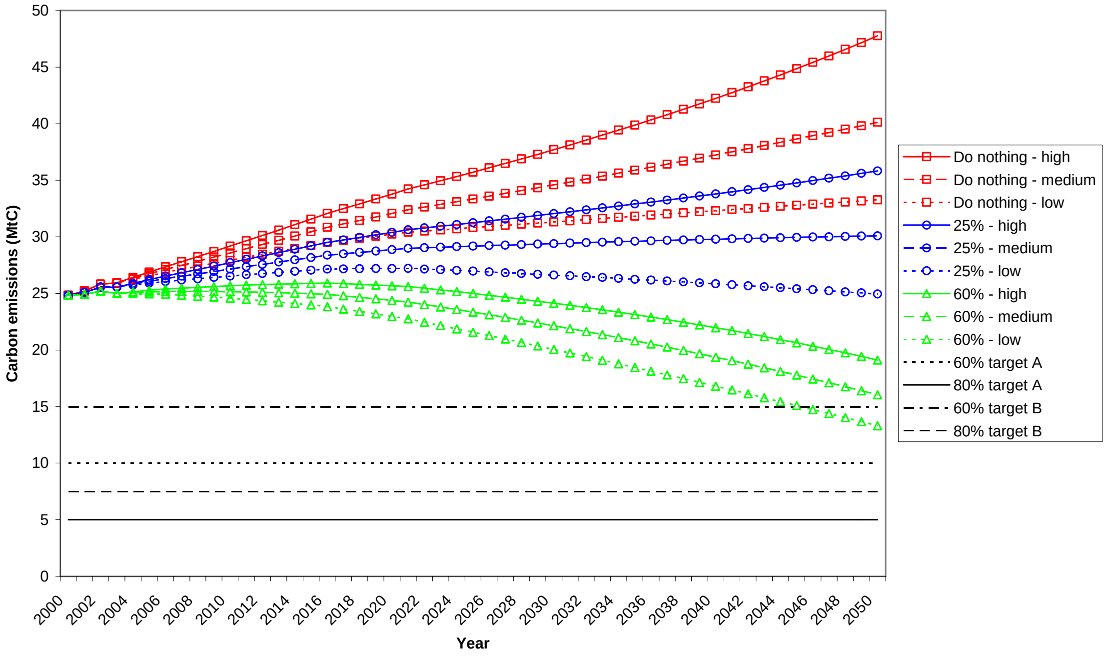
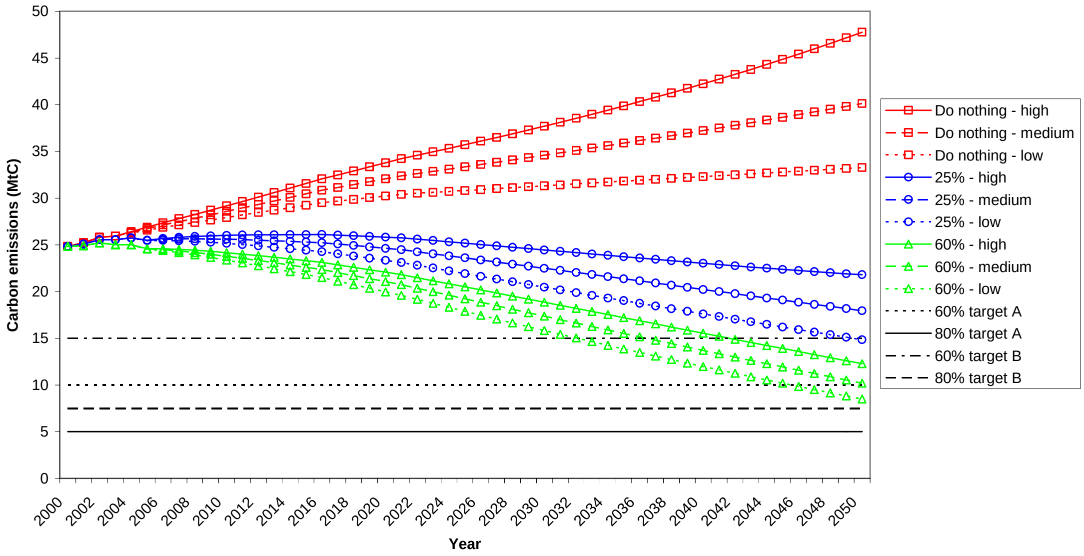
2050
Year
Do nothing - high
Do nothing - medium
Do nothing - low
60% target A
80% target A
60% target B
80% target B


Carbon emissions (MtC)
Year
Do nothing - high
Do nothing - medium
Do nothing - low
25% - high
25% - medium
25% - low
60% - high
60% - medium
60% - low
60% target A
80% target A
60% target B
80% target B



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Carbon emissions (MtC)
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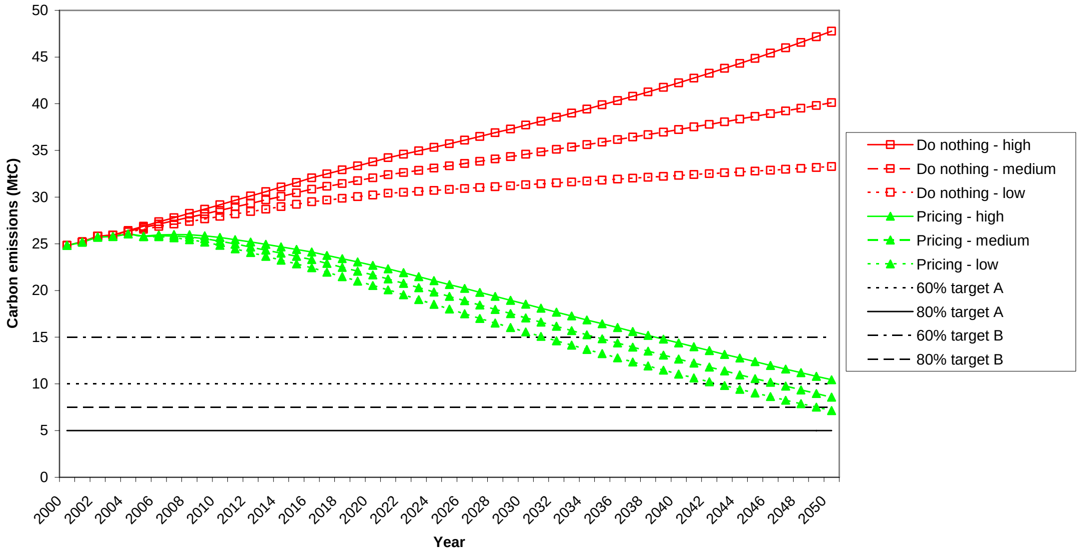
Year
Do nothing - high
Do nothing - medium
Do nothing - low
25% - high
25% - medium
25% - low
60% - high
60% - medium
60% - low
60% target A
80% target A
60% target B
80% target B


Carbon emissions (MtC)
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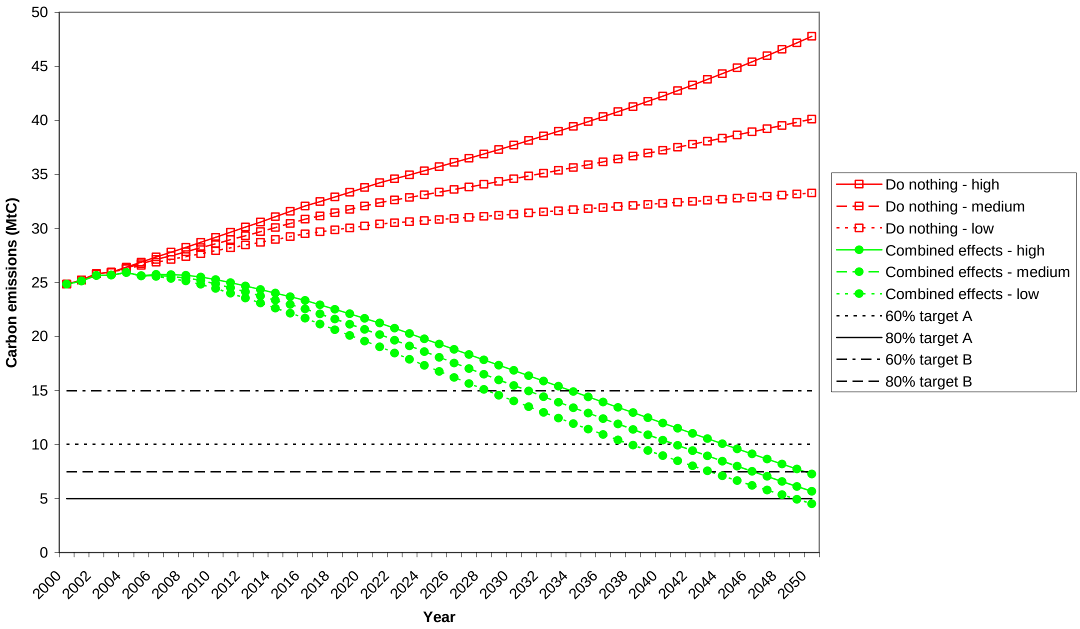
Year
Do nothing - high
Do nothing - medium
Do nothing - low
Pricing - high
Pricing - medium
Pricing - low
60% target A
80% target A
60% target B
80% target B


Carbon emissions (MtC)
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Year
Do nothing - high
Do nothing - medium
Do nothing - low
Combined effects - high
Combined effects - medium
Combined effects - low
60% target A
80% target A
60% target B
80% target B