Energy Efficiency: DEFRA Paper on Transport Energy Efficiency

This paper describes ongoing research work being carried out by DEFRA on energy efficiency in the transport sector. This work is contributing to the PIU's reviews of resource productivity and energy through the Interdepartmental Analysts Group (IAG) led by the DTI. The research takes a scenario approach using projections and assumptions to investigate a range of possible futures over a 50 year timescale. These projections and assumptions have been developed for the purposes of this research and do not represent Government policy.

Outline

This paper describes DEFRA's work on transport energy efficiency. The aim of this work is to explore the scope for additional energy efficiency measures in the transport sector in 2050, and the approximate cost of such measures. In order to do this, we must first understand the level of technological and behavioural change that is assumed to have happened without such additional measures. The first stage of our analysis has therefore been to develop baseline and scenario-based energy and carbon projections for the transport sector using DTLR road traffic projections and experts' forecasts of technological development over the next fifty years. This has provided a picture of future transport activity growth, modal split, energy use and carbon emissions under different scenarios. Our baseline projections are broadly in line with those of the DTI but there are differences in some of the scenario projections and we are working with the DTI to understand the reasons for these differences. This paper also presents some possible additional measures to improve energy efficiency and reduce carbon emissions below baseline levels.

1. Approach

In common with DEFRA's work on other sectors, we have taken a simple approach that links the end use carbon to the ultimate driver, GDP, via a small number of variables which allow separate consideration of fuel switching, technological improvements and structural changes in the sector.

We can represent the relationship as:

$$C = (C / E) * (E / U) * (U / X) * (X / GDP) * GDP$$

where

C	= tonnes of carbon
E	= energy use
U	= the amount of "transport energy service" required in vehicle-km adjusted for modal split
X	= the number of appropriate consumption "units" such as households
GDP	= Gross Domestic Product

Transport energy service (U) could perhaps more usefully be expressed as passenger-km for passenger transport and tonne-km for freight transport, which would introduce an additional occupancy (passenger-km/vehicle-km) or loading (tonne-km/vehicle-km) factor. It may also be sensible to consider passenger and freight transport differently when it comes to economic growth; both relate to GDP but only passenger transport relates to household numbers. However, for simplicity and consistency with DTI, we have worked with vehicle-km and a single factor growth relationship so far.

This approach would allow us to project future carbon emissions from estimates of economic growth, vehicle fleet composition, specific energy consumption and fuel choice (which determines the carbon/energy ratio). However, it is also important to incorporate constraints to transport growth in terms of the road and rail networks.

2. DTI Projections for the Transport Sector

The DTI has prepared projections of carbon emissions from the transport sector to 2050 for a baseline scenario and the four foresight scenarios. These projections are based on historical (1970-2000) and near-term future (2000-2010 or 2000-2020) carbon intensity change rates, with 2050 estimates of GDP and household numbers. Both historical and near-term future carbon intensity trends will include elements of technology improvement (energy efficiency changes), occupancy changes, modal shift and fuel switching. The latter will be minimal as petroleum products constitute 99.5% of transport energy use and there is little difference in carbon intensity between petrol and diesel. The DTI's approach and assumptions are detailed in the paper "Estimate of the scale of the carbon reduction required".

Unlike other sectors, the DTI has also included scenario-dependent factors to account for technological development (the "polluting" factor) and growth in transport demand (the "growth" factor). These factors recognise the likelihood that different attitudes to globalisation and environmental issues will be reflected in different rates of technological progress and different attitudes to transport, particularly car use, in the future.

There are therefore existing energy efficiency improvements built in to the DTI's projections, both implicit in the projection of historical trends and explicit in the use of a technological development factor.

3. Road Traffic Growth Projections

As explained above, a simple approach to traffic growth projections based on historical or near-future trends does not allow for the constraints to traffic growth, particularly road traffic growth, anticipated over coming decades. These constraints are complicated to model because road congestion may lead people to travel at a different time, take a different route, switch transport modes or reduce their journeys (or some combination of these).

The DTLR's National Road Traffic Forecast (NRTF) model incorporates behavioural factors within a comprehensive model of vehicle types, vehicle use (for cars only), economic growth, fuel prices, road types and road capacities. We have therefore used the NRTF as a basis for our baseline projection of future transport demand. This is consistent with the approach adopted by the PIU.

As the NRTF projections only go up to 2031, it has been necessary to make additional assumptions about demand growth rates in 2031-2050 for the baseline scenario. We have also looked at road transport demand under the different scenarios. The resulting road transport demand projections and assumptions are shown in Table 1, with further detail given in Appendix 1. These traffic projections have been drawn up by DEFRA specifically for the purposes of this research, and do not represent official Government projections of future traffic growth.

Table 1: Road transport demand projections and assumptions

Scenario	bkm/year in 2050 (index 1999 = 100)				Comments/assumptions
	Cars	LGVs	HGVs	PSVs [1]	
Baseline	598.5 (154)	119.2 (266)	67.6 (207)	8.3 (163)	Based on NRTF: GDP +2.25%pa; 1996 road capacity
World markets	718.2 (185)	143.0 (319)	81.2 (248)	8.3 (163)	Additional road capacity; higher GDP growth
Global sustainability	430.9 (111)	107.3 (239)	60.9 (186)	18.3 (358)	1996 road capacity; modal shift
Provincial enterprise	658.4 (170)	131.1 (292)	74.4 (228)	8.3 (163)	Additional road capacity
Local stewardship	251.4 (65)	81.1 (181)	40.6 (124)	12.2 (239)	1996 road capacity; modal shift

[1] PSVs = public service vehicles, primarily buses.

4. Technological Development in Road Transport

Table 2 shows our assumptions about technological development in road transport to 2050, and the implied change in average specific fuel consumption (l/100km of gasoline equivalent) for each transport mode. Further details are provided in Appendix 1.

Table 2: Specific energy consumption of road transport technology in 2050

Scenario	L/100km in 2050 (index 1999 = 100)				Comments/assumptions
	Cars	LGVs	HGVs	PSVs	
Baseline	4.2 (49)	5.4 (64)	27.8 (77)	18.3 (65)	Mostly advanced ICE vehicles. Baseline size cars.
World markets	4.3 (51)	5.1 (61)	26.8 (74)	17.2 (62)	Advanced ICE vehicles; gasoline fuel cell (FC) cars. Cars > baseline size.
Global sustainability	3.2 (39)	4.9 (58)	25.8 (71)	16.2 (58)	Advanced ICE, H_2 FC cars, more renewables. Cars < baseline size.
Provincial enterprise	6.3 (74)	6.4 (77)	30.6 (85)	21.5 (77)	Less advanced ICE vehicles. Cars > baseline size.
Local	3.9	5.4	30.6	21.5	Mix of less advanced ICE,

stewardship	(46)	(65)	(85)	(77)	advanced ICE, H_2 FC cars and renewables. Cars < baseline size.

We have assumed more technical innovation for the global (WM and GS) scenarios and more emphasis on renewable fuels in the environmental scenarios (GS and LS). We have also allowed for customer preferences for smaller cars in the environmental scenarios.

5. Non-road transport energy demand

Rail and domestic air transport energy demand are assumed to increase from a relatively low base under the non-environmental scenarios, as shown in Table 3. Water and motorcycle transport are assumed unchanged.

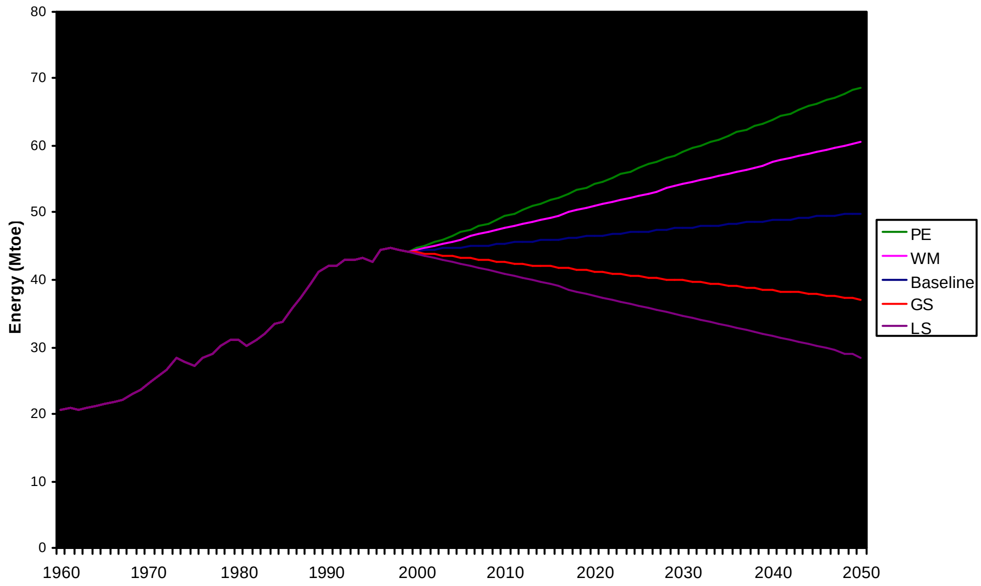
Table 3: Rail and domestic air transport energy projections and assumptions

Scenario	Mtoe in 2050 (index 1999 = 100)		Comments/assumptions
	Rail transport	Domestic Air	
Baseline	1.2 (166)	4.3 (269)	1% pa increase in rail 2% pa increase in domestic air
World markets	1.2 (166)	7.0 (438)	1% pa increase in rail 3% pa increase in domestic air
Global sustainability	2.0 (275)	2.1 (129)	2% increase in rail 0.5% pa increase in dom. air
Provincial enterprise	1.0 (129)	4.3 (269)	0.5% pa increase in rail 2% pa increase in domestic air
Local stewardship	2.0 (275)	1.6 (100)	2% pa increase in rail No increase in domestic air

6. Energy and Carbon Projections

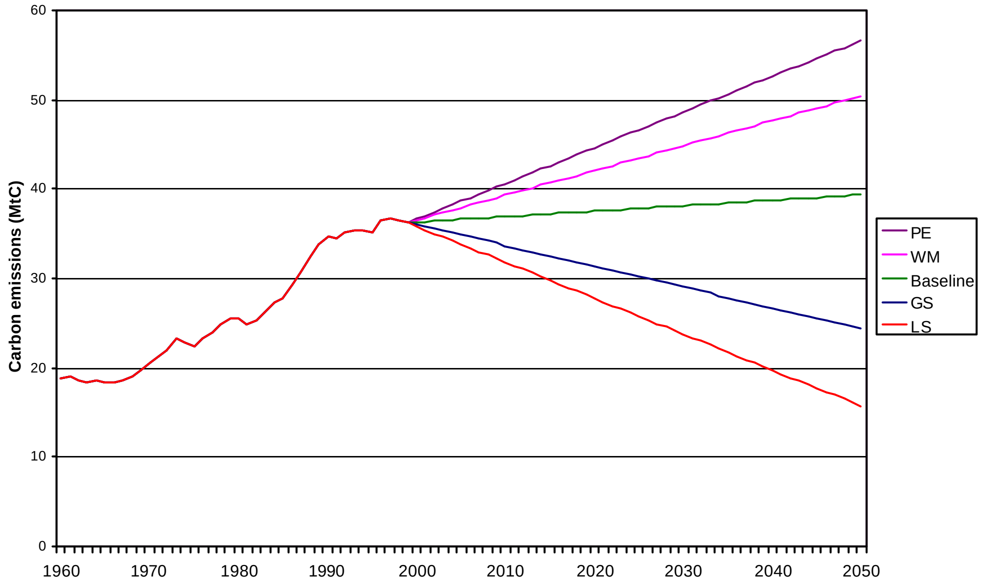
Figure 1 shows transport energy projections to 2050 based on the activity and technological development assumptions outlined above.

Figure 1: Transport sector energy use to 2050



Carbon projections would show similar trends to Figure 1 if petroleum continues to be the dominant transport fuel to 2050. However, some fuel switching to lower carbon options, such as hydrogen and biofuels, is anticipated under the Global Sustainability and Local Stewardship scenarios. Figure 2 shows our carbon projections to 2050.

Figure 2: Carbon emissions from transport to 2050



Our baseline carbon projections are in line with DTI's projections, falling between DTI Variant A (continuation of past trends) and Variant B (continuation of 2000-2020 future trends) projections, as shown in Table 4. This is to be expected since transport demand is unlikely to continue at past rates due to network constraints and technology is unlikely to continue to improve at 2000-2020 rates due to thermodynamic limits.

There are differences between DEFRA and DTI scenario projections. In particular our Global Sustainability and Local Stewardship projections are lower than DTI's while our Provincial Enterprise projections are substantially higher.

Table 4: Comparison of DEFRA and DTI transport sector carbon projections

Scenario	Projected MtC in 2050		
	DTI Variant A	DTI Variant B	DEFRA
Baseline	53	32	39.4
WM	59	41	50.4
GS	39	27	24.4
PE	46	37	56.6
LS	30	21	15.7

Note: DTI projections were taken from an earlier paper and may change as a result of recent efforts to align assumptions on household numbers with DEFRA and PIU.

7. Scope for additional energy efficiency and carbon reduction

Additional policy measures could be introduced to reduce carbon emissions from the transport sector by encouraging:

- additional penetration of fuel cell vehicles
- additional use of renewable fuels (carbon reduction only)
- additional modal shift from cars to public transport
- additional efforts to reduce total distance travelled

Table 5 shows the possible impacts of different measures, and the resultant carbon emission reductions from the baseline level of 39.4 MtC. These emission reductions are very approximate but they do illustrate the range of possibilities and the sensitivities to assumptions made about the baseline scenario.

These results are based on baseline assumptions for demand growth and technology improvement to 2050. The scope for introducing additional measures will be scenario dependent, as will their likely impact. For example, policies to encourage modal shift are more easily introduced in an environmentally aware scenario but they may have less impact because much of the shift has already happened.

Table 5: Additional measures to reduce baseline carbon emissions

Possible measures	Illustrative impact	Carbon Reduction	
		MtC	% of baseline
More R&D funding. Vehicle taxes. Fuel taxes.	An additional 10% of gasoline cars and LGVs replaced by gasoline fuel cell vehicles.	0.5	1%
More R&D funding. Vehicle taxes. Fuel taxes.	10% of gasoline cars and LGVs replaced by hydrogen fuel cell vehicles.	1.0	3%

Fuel taxes.	An additional 10% of diesel cars and LGVs converted to biofuel.	0.9	2%
Fuel taxes. Public education. Bus priority schemes.	10% modal shift from cars to buses.	1.0	3%
Public education. Town planning.	A 10% reduction in car use (vehicle-km).	6.5	16%
Industry education. More R&D funding on advanced IT.	A 10% reduction in HGV energy consumption due to better logistics management.	1.2	3%

8. Costs of additional energy efficiency and carbon reduction

It is difficult to cost these measures in any meaningful way as we run into several problems:

- How do we estimate the absolute or marginal cost of new technologies that are not commercially available today?
- How do we account for the sunk cost of infrastructure provision (e.g. hydrogen) or fuel cell R&D included in some scenarios and not others?
- How can we cost non-technical measures to encourage behavioural changes when "normal" behaviour is so scenario dependent?

DEFRA has therefore taken a generic approach to estimating the cost of additional energy efficiency measures across all sectors. This is described in Hunter Danskin's paper to the IAG meeting on 18 July.

Appendix 1 – Detailed assumptions for each scenario

A1.1 Road traffic

All scenarios are based on the NRTF central forecast of growth in car, HGV, LGV and PSV traffic to 2031. NRTF forecasts are scaled up by 2% to reflect the fact that the NRTF gives data for Great Britain rather than the UK. The trends of diminishing annual growth rate from 2000 to 2031 are assumed to continue to 2050, reflecting road capacity constraints.

The following factors are then applied to account for differences in demand due to differences between scenarios in economic growth rate, propensity to build new road capacity and environmental awareness.

Table A1.1 Index of road traffic demand in 2050, excluding modal shift effects (baseline =100)

	Cars	LGVs	HGVs	PSVs
Baseline	100	100	100	100
WM	120	120	120	100
GS	90	90	90	90
PE	110	110	110	100
LS	60	60	60	60

For both environmentally aware scenarios (GS and LS), 20% of car traffic is assumed to shift to PSVs, with an occupancy ratio of 10:1 between buses and cars. 10% modal shift from cars to LGVs is assumed for the LS scenario to take account of increased e.commerce and home shopping, with an occupancy ratio of 3:1 between LGVs and cars.

A1.2 Road transport technologies and fuels

The following fleet composition is assumed for each scenario in 2050:

Table A1.2 Fleet compositions for 2050 by scenario

Baseline	There is some penetration of gasoline fuel cell cars and LGVs (20% of gasoline fuelled versions). The remaining vehicles use a mixture of 75% advanced IC engines and 25% less advanced IC engines (see below for definitions); 10% of diesel is replaced by bio-fuel. Cars fuelled by gasoline (70% of distance travelled), diesel (27%) and bio-fuels (3%). LGVs fuelled by gasoline (30% of distance travelled), diesel (63%) and bio-fuels (7%). HGVs and PSVs both fuelled by diesel (90% of distance travelled) and bio-fuels (10%).
WM	Cars fuelled by gasoline (70% of distance travelled) and diesel (30%). 10% of gasoline cars powered by fuel cells; remaining 90% by advanced IC engines (ICE). LGVs fuelled by gasoline (30% of distance travelled) and diesel (70%). 10% of gasoline LGVs powered by fuel cells; remaining 90% by advanced ICE.

	HGVs and PSVs both diesel fuelled with advanced IC engines. No bio-fuel or hydrogen fuel cell vehicles.
GS	20% of all vehicles are hydrogen fuel cell vehicles; 20% of diesel has been replaced by bio-fuel. Car fleet therefore comprises: advanced gasoline ICE (56% of distance travelled), advanced diesel ICE (19%), advanced bio-fuel ICE (5%) and hydrogen fuel cell vehicles (20%). LGV fleet comprises: advanced gasoline ICE (24% of distance travelled), advanced diesel ICE (45%), advanced bio-fuel ICE (11%) and hydrogen fuel cell vehicles (20%). HGV and PSV fleets comprise: advanced diesel ICE (64% of distance travelled), advanced bio-fuel ICE (16%) and hydrogen fuel cell vehicles (20%).
PE	All vehicles use less advanced IC engines (see below for definition of less advanced ICE); no penetration of bio-fuels. Cars fuelled by gasoline (80% of distance travelled) and diesel (20%). LGVs fuelled by gasoline (30% of distance travelled) and diesel (70%). HGVs and PSVs both fuelled by diesel.
LS	All vehicles use a mixture of 50% advanced IC engines and 50% less advanced IC engines (see below for definitions); 50% of diesel has been replaced by bio-fuel. Cars fuelled by gasoline (56% of distance travelled), diesel (12%), bio-fuels (12%) and hydrogen (20%). LGVs fuelled by gasoline (24% of distance travelled), diesel (28%), bio-fuels (28%) and hydrogen (20%). HGVs and PSVs both fuelled by diesel (40% of distance travelled), bio-fuels (40%) and hydrogen (20%).

Fuel consumption and specific energy consumption data for current generation vehicles are derived from Transport Statistics Great Britain, Netcen modelling and the Digest of UK Energy Statistics (see Table A1.2). These data are based on a fleet averages rather than new vehicle data (new vehicle fuel consumption would be significantly lower).

Table A1.3 Fuel consumption, specific energy consumption and CO_2 emissions for current road vehicles (1999 data)

	l/100km	MPG	MJ/km	GCO_2/km
Gasoline car	8.5	33.2	3.0	206
Diesel car	7.0	40.4	2.7	201
Gasoline LGV	8.9	31.7	3.1	216
Diesel LGV	7.4	38.4	2.8	211
Diesel HGV	32.6	8.7	12.6	936
Diesel PSV	25.2	11.2	9.8	723

Fuel consumption data for cars in 2050 is based on the following assumptions:

- Advanced gasoline and diesel IC engines achieve a 30% improvement over the 2008 target for new cars set by the ACEA agreement with motor manufacturers; this is approximately equivalent to the USDOE's 80 MPG target for the PNGV programme. These are likely to be hybrid vehicles made from lightweight materials.

- Less advanced gasoline and diesel IC engines achieve the 2008 ACEA target but no more than that. This may be because fuel efficiencies do not continue to improve, or because there is a trend to larger, better equipped vehicles, or some combination of these effects.
- Gasoline and hydrogen fuel cell vehicles achieve fuel efficiencies equivalent to 2.8 l/100km and 2.2 l/100km, based on US studies of future transport options.
- All bio-fuels and hydrogen are derived from renewable energy sources, resulting in zero carbon emissions (note this is not really true for biofuels since there will be carbon emissions associated with cultivation, harvesting and distribution).

Table A1.4 Fuel consumption and specific energy consumption assumptions for cars in 2050

	l/100km	MPG	MJ/km	gCO_2/km
Less advanced gasoline ICE	5.8	48.9	2.0	140
Less advanced diesel ICE	4.9	57.9	1.9	140
Less advanced bio-fuel ICE	4.9	57.9	1.9	0
Advanced gasoline ICE	4.0	69.9	1.4	98
Advanced diesel ICE	3.4	82.7	1.3	98
Advanced bio-fuel ICE	3.4	82.7	1.3	0
Gasoline fuel cell	2.8	100.9	1.0	68
Hydrogen fuel cell	2.2	128.4	0.8	0

Although the available technology may be similar, average fuel consumption under environmentally aware scenarios should be lower because people will choose smaller cars. This effect has been incorporated using a size factor applied to the fuel consumption of cars: baseline = 1, WM/PE = 1.1; GS/LS = 0.9.

Fuel consumption for LGVs and PSVs is assumed to improve at 75% of the rate of improvement in fuel consumption for cars under all scenarios. HGV fuel consumption is assumed to improve at 50% the rate of cars. These reductions allow for the fact that these vehicles cannot benefit fully from the weight reduction and aerodynamic improvements possible for cars.

SEP/DEFRA
October 2001