Logistics 2050

Moving Freight by Road in a Very Low Carbon World

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1. Introduction

Climate change is now widely considered to be the most serious challenge facing mankind. According to the Intergovernmental Panel on Climate Change (IPCC) (2007), scientific evidence of the relationship between fossil fuel combustion, carbon dioxide emissions and global warming is now ‘unequivocal’. Global anthropogenic emissions of greenhouse gases (GHG) have grown at an accelerating rate since pre-industrial times. Since 1750 carbon dioxide concentrations in the atmosphere have increased by over one third (from 280 parts per million (ppm)), predominantly as a result of us burning fossilised carbon deposited in the earth over a period of 300 million years. (Walker and King, 2008). CO_2 levels in the atmosphere now stand at 387 ppm and are rising at about 2 ppm each year. Stern (2006) examined the relationship between atmospheric concentrations of CO_{2e} and the probability of increases in average global temperature exceeding certain levels[1]. Current climate models suggest that if the concentration can be limited to 450ppm by 2050, it is likely that the temperature rise by 2100 will be around 2^o C (Committee on Climate Change, 2008). This will still be very damaging to the environment, but it should avert the catastrophic effects of ‘run-away’ climate change.

In framing climate change policies, many national governments and inter-governmental organisations are seeking to limit the global CO_{2e} concentration to 450 ppm by 2050, despite the fact that Stern (2006) argues that ‘*stabilisation at 450 ppm CO2e is already almost out of reach’.* It will require a huge reduction in CO_{2e} emissions over the next 40 years, particularly from developed countries. According to the Hadley Centre, at a global level, annual emissions will have to fall from 48 billion tonnes of CO_{2e} today to 24-28 billion tonnes in 2050. Spreading the remaining CO_{2e} emissions evenly across the forecast world population of 9.2 billion in 2050, would give everyone an annual allocation of 2.1-2.6 tonnes. For the UK this would entail an 80% reduction in CO_{2e} emissions relative to 1990 and roughly 75% relative to 2007 (Climate Change Committee, 2008; DEFRA, 2009). This scale of reduction is now enshrined in legislation. The 2008 Climate Change Act commits the current and future UK governments to a ceiling on carbon emissions in 2050 which is only a fifth of the actual emissions in 1990. An independent committee has been appointed,

[1] CO_2 equivalent, abbreviated to CO_{2e}, expresses the amount of CO_2 that would have the same global warming potential as the greenhouse gas in question, measured over a specified timescale (typically 100 years). CO_2 is by far the most important GHG emitted by road transport, accounting for roughly 96% of the total road transport-related CO_{2e} emissions.

the Committee on Climate Change, to develop a series of rolling five-year carbon budgets to ensure that the country is on course to meet the 2050 target.

The transition to a very low carbon economy over four decades will require fundamental changes in technology, infrastructure, business practices, fiscal and regulatory frameworks, consumption patterns and lifestyles. Research on the nature and extent of the necessary changes is still at an early stage. It is possible, however, to assess the magnitude of the changes that will be required in particular sectors for their carbon emissions to drop by 75% by 2050. We have done this analysis for the UK road freight transport sector using official statistics and data collected in a Delphi survey of expert opinion. In this chapter, we summarise the results of this analysis and consider the likelihood of the required changes in key parameters being achieved by 2050.

2. Carbon footprint of road freight operations

Globally the transport sector was responsible for approximately 23% of energy-related GHG emissions in 2004 (Kahn Ribeiro et al., 2007). Road freight transport accounted for a quarter of world-wide energy consumption by transport in 2000 (Fulton and Eads, 2004) and its energy use is expected to increase by nearly 150% between 2000 and 2050 (WBCSD, 2004). Over the past decade, GHG emissions from transport have been increasing at a faster rate than from any other energy-using sector. Furthermore, the amount of energy used by trucks has been growing more rapidly than that used by cars and, if current trends continue, will exceed car-related energy consumption by 2020 (WBCSD,2004). When set against these global forecasts, the prospects of achieving massive cuts in carbon emissions from road freight transport seem remote.

It will also be extremely difficult at a national level to decarbonise trucking operations by the requisite amount. This is well illustrated by the case of the UK. Depending on the scope of analysis, the nature of the calculation and the assumptions made, estimates of total CO_2 emissions from trucks in the UK in 2006 vary between 18.6 and 25.8 million tonnes (McKinnon and Piecyk, 2008). The UK Department for Transport (2008a) has forecast that, on a business as usual (BAU) basis, CO2 emissions from HGVs will rise to around 33 million tonnes by 2020. The Committee on Climate Change (2008), on the other hand, is projecting a more modest increase to around 25 million tonnes by 2025. The results of a Delphi survey of 100 logistics specialists suggested, again on a BAU basis, that there would be a net reduction of 8% in CO_2 emissions from UK road freight transport between 2006 and 2020 (Piecyk and McKinnon, 2009). Even extrapolating this more optimistic trend forward to 2050 would only cut CO_2 emissions from HGVs by 28% in 2050 (relative to 2007), well short the 75% reduction required to meet the government's target. The question then arises of what changes would have to be made to the UK trucking sector by 2050 to cut its CO_2 emissions by four-fifths.

3. Analytical framework

In the course of a Green Logistics research project[2], a decompositional framework has been developed which maps the complex relationship between the weight of goods produced / consumed in an economy and CO_2 emissions from road freight transport operations (Figure 1). The version of the framework applied in the current analysis is based on six key parameters:

1) *Freight transport intensity* measures the propensity of an economy to generate freight movement and is generally expressed as the ratio of tonne-kms to GDP. As no forecasts exist for the UK GDP in 2050, the future tonne-km trend has been projected as an independent variable.

2) *Modal split* indicates the proportion of freight carried by different transport modes. As the focus of this analysis is road freight transport, this variable is simply defined as the proportion of tonne-kms likely to be moved by road.

3) *Average payload on laden trips* is normally measured solely in terms of weight as very little data is available on the cubic volume of freight moved by road

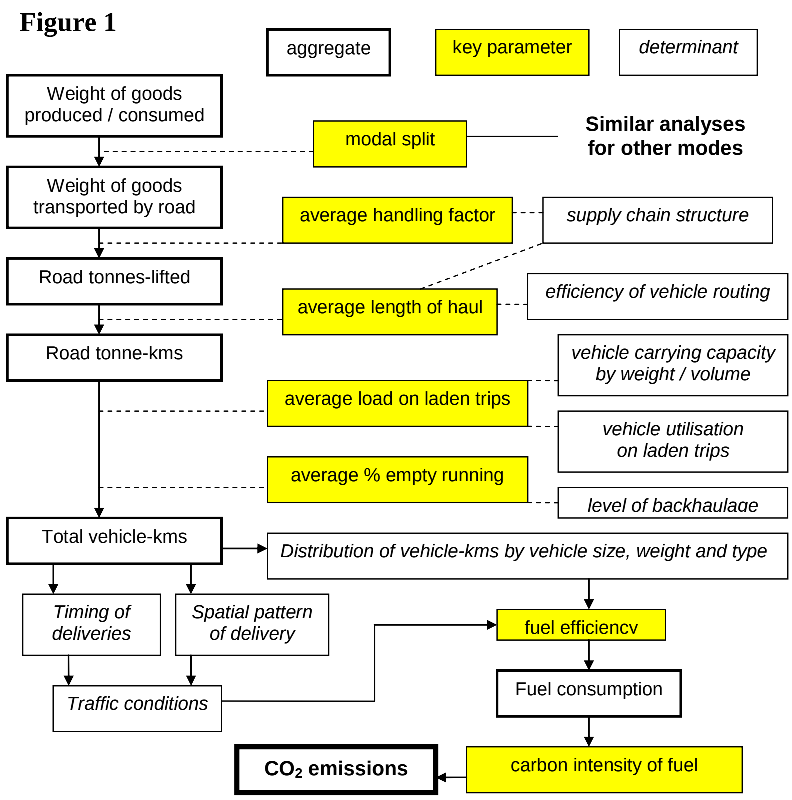
4) *Empty running,* measured by the percentage of truck-kms run empty

5) *Energy efficiency*, defined as the ratio of the distance travelled by HGVs to the energy they consume.

[2] This project involves six UK universities and is funded by the Engineering and Physical Sciences Research Council. Details can be found at www.greenlogistics.org

6) *Carbon intensity of the energy source,* i.e. the amount of CO_2 emitted per unit of energy consumed either directly by the vehicle or indirectly at the primary energy source for electrically-powered freight operations.

Figure 1: Framework for the Analysis of Carbon Reduction Potential in the Road Freight Sector



Modifications to these parameters would be mutually-reinforcing and in combination could achieve substantial decoupling of trucking-related CO_2 emissions from future GDP growth. In modelling the opportunity for decoupling one must first establish to what extent the key parameters can realistically be modified over the next forty years. This has been done by constructing a series of scenarios with reference to published forecasts and an original survey of expert opinion.

a) Published forecasts:

Two sets of published forecasts have been consulted

Mobility 2030: this forecast compiled by the WBCSD (2004) relates to traffic volumes and energy consumption and is the only one to project forward to 2050. Forecasts are disaggregated by continent and a distinction made between OECD and non-

OECD countries. The annual average tonne-km growth rate for European OECD countries is forecast to be 1.5% per annum between 2000 and 2050. This figure relates to road and rail freight traffic.

Tremove: this European Commission-funded project has compiled forecasts of transport emissions up to 2030. They include estimates of future reductions in the carbon content of energy used by road freight vehicles. Linear extrapolation has been used to extend Tremove (2009) forecasts of this variable from 2030 to 2050.

b) Original survey:

As part of the Green Logistics project, a two-round Delphi survey was conducted of a sample of 100 logistics specialists in the UK seeking their views on a range of freight transport, logistical and environmental trends to 2020 (Piecyk and McKinnon, 2009). Trends in several key variables were extrapolated to 2050, again on a linear basis.

4. Calibration of the Model

Table 1 lists the options modelled for each of the six key road freight parameters. Adopting high, medium and low values for every parameter would have generated 729 scenarios and rendered the analysis and reporting unwieldy. Instead, this three-level gradation was only applied to the underlying growth in tonne-kms. To keep the analysis manageable only high and low options are adopted for empty running, average payload weight and fuel efficiency, while a single projection has been used for modal shift and the decarbonisation of energy.

Table 1: Options Modelled for the Key Road Freight Parameters

<table>
<tr><th>Parameter</th><th>unit of measurement</th><th colspan="4">levels</th></tr>
<tr><td></td><td></td><td>high</td><td colspan="2">medium</td><td>low</td></tr>
<tr><td>Freight movement</td><td>tonne-kms (t-km)</td><td>Mobility 2030 forecast +65%</td><td colspan="2">Projection of 1997-2007 trend +27%</td><td>Stable at 2007 level</td></tr>
<tr><td>Freight modal split</td><td>% of t-km by road</td><td colspan="4">reduced from 64% to 50%</td></tr>
<tr><td></td><td></td><td colspan="2">high</td><td colspan="2">low</td></tr>
<tr><td>Empty running</td><td>% of truck-km</td><td colspan="2">reduced from 27% to 22%</td><td colspan="2">reduced from 27% to 17%</td></tr>
<tr><td>Mean payload weight</td><td>tonnes (70% load factor)</td><td colspan="2">raised from 9.8 tonnes to 12.1 tonnes within existing weight limits</td><td colspan="2">raised from 9.8 tonnes to 16.1 tonnes 25% of t-km in longer / heavier vehicles</td></tr>
<tr><td>Fuel efficiency</td><td>kms / litre</td><td colspan="2">increased by 40%</td><td colspan="2">increased by 20%</td></tr>
<tr><td>Carbon intensity</td><td>CO_2 / kWh</td><td colspan="4">reduced by 30%</td></tr>
</table>

The specification of the various parameter options is as follows:

Total tonne-kms: The Mobility 2030 study predicted that European OECD countries, such as the UK, would experience a 65% growth in total tonne-kms by 2050 (WBCSD, 2005). This was adopted as the upper end of the range of tonne-km values for 2050. Projecting the average annual rate of growth in total tonne-kms (by all modes) actually experienced over the past ten years increased the amount of freight movement 27% by 2050. This was taken to be the mid-range forecast. The low estimate assumes no net growth in tonne-kms above the 2008 level. This can be justified on the grounds that there may be a pronounced decoupling of GDP and tonne-km trends by 2050, for reasons discussed in McKinnon (2005) and that economic growth itself may be inhibited by climate change and public policies implemented to control it. Recent evidence of a 'recoupling' of GDP and road tonne-km growth in the UK, however, suggests that this low estimate may be over-optimistic (McKinnon, Piecyk and Somerville, 2008).

Modal shift: Extrapolating the Delphi forecast to 2050 suggests that by then road's share of total tonne-kms will have declined from 64% to 50%. This would be consistent with the UK government's goal of transferring a substantial proportion of freight from road to rail and water partly to cut carbon emissions (Department for Transport, 2008b). It would effectively return road's share of the UK freight market back to its 1960 level.

Empty running: There has been a marked improvement in the backloading of lorries over the past few decades, for a variety of reasons outlined by McKinnon (1996). The majority of the Delphi panellists believed that the potential still exists to cut the remaining empty running by a significant margin. If the rate of decline in empty running they predicted continued beyond 2020 it would drop from 27% in 2007 to 11% by 2050. As much empty running is structural and will be very difficult to eliminate, particularly given the short average length of haul for road freight in the UK (87km) (McKinnon and Ge, 2005), it was decided that such a large reduction would be impractical. A minimum level of empty running was set at 17% and an upper level at 22%, the latter figure assuming that it would stabilise at the level of empty running predicted by the Delphi survey for 2020. To put these forecast reductions into an historical context, it took 28 years (from 1973 to 2001) for the empty running % to decline from 34% to27% (McKinnon and Ge, 2005).

Payload weight: Over the next forty years, several developments are likely to promote the consolidation of loads into larger and heavier consignments that make better use of vehicle capacity. Steep increases in the price of oil and carbon emissions will force a relaxation of just-in-time scheduling, encourage greater logistical collaboration within and between supply chains and suppress sales and marketing practices that have traditionally resulted in the under-utilisation of vehicle capacity. Quantifying the consequent improvement in vehicle loading is very difficult, however. If the consolidation of freight into heavier consignments forecast by the Delphi panel were to continue at a uniform rate to 2050, average payload weight would rise from 9.8 to 13.5 tonnes and the proportion of weight-carrying capacity used on laden trips would increase from 57% to 79%. As in the case of empty running, it was considered that such an increase would not be feasible within current vehicle size and weight limits, particularly as the average density of freight is currently declining. It would represent a major achievement for companies operating trucks, if the average lading factor could be raised to 70% and average payload weight to 12 tonnes. Allowance was, nevertheless, made for the possibility that the maximum weight lorries in the UK would be raised to 60 tonnes by 2050 (and their maximum length to 25 metres), limits recently investigated by recent studies of longer and heavier vehicles (LHVs) in the UK (Knight et al, 2008) and EU (Transport Mobility Leuven, 2008). LHVs of this type have operated successfully in Sweden and Finland for many years. The upper limit on payload weight assumes that 25% of road tonne-kms would by moved by 60 tonne / 25 metre LHVs operating with a weight-based loading factor of 70% on laden trips. .

Fuel efficiency: Over the past decade the average fuel efficiency of trucks in the UK has increased by roughly 0.5% per annum (Department for Transport, 2008c). If this rate of improvement could be maintained to 2050, road freight operations would by then be 24% more fuel efficient. Projecting the anticipated Delphi trend in fuel efficiency forward to 2050 yields a lower fuel efficiency gain of 16%. Neither of these forecasts, however, take account of advances in vehicle technology over the next 20-30 years which could deliver a step change in the energy efficiency of trucks. Research by Woodroofe and Associates for the US Department for Energy (quoted in Duleep, 2007), for example, indicates the possible future energy savings from improved truck technology and design (Table 2). It suggests that a 36% reduction in energy use might be achieved, two-thirds of which would accrue from improved engine design. Lower and upper bounds for gains in fuel efficiency by 2050 have therefore been set at 20% and 40% to reflect, respectively, incremental BAU improvements and their reinforcement by a quantum leap in vehicle technology.

Table 2: Target Reductions in the Energy Consumption of Heavy Trucks in the US
(Source: Woodroofe and Assocs., quoted by Duleep, 2007)

	base	**target**	**% reduction**	**saving**	**% of total saving**
Engine losses (kWh)	240	143	40%	97	67%
Aerodynamic losses (kWh)	85	68	20%	17	12%
Tyres - rolling resistance (kWh)	51	31	39%	20	14%
Transmissions (kWh)	9	6.3	30%	2.7	2%
Auxiliary equipment (kWh)	15	7.5	50%	7.5	5%
Total	400	255.8	36%	144.2	100%

<u>Carbon intensity of the energy source:</u> The amount of CO_2 emitted per unit of energy consumed in road freight transport is likely to fall as a result of two processes: the switch from fossil fuels to biofuels and the electrification of trucks. Initial optimism that the use of biofuels could make a large contribution to the decarbonisation of freight transport has given way to scepticism about whether they actually yield a net carbon saving and concern about their wider adverse effects on ecosystems and food supplies (ITF, 2007; Gallagher Committee, 2008). It is anticipated, however, that over the next decade or so 'second generation' biofuels, derived from agricultural waste and forest products, will be successfully commercialised and meet wider sustainability criteria. Also over this period, much of the rigid truck fleet will be 'hybridised' i.e. drawing power from conventional diesel engines on longer hauls and batteries for shorter, stop-start deliveries (Committee on Climate Change, 2008). As the primary energy mix for electricity generation shifts from fossil fuels to renewables and nuclear, the amounts of CO_2 emitted in the recharging of these batteries will gradually decline. As rigids consumed only around 45% of truck fuel in 2006 (Department for Transport, 2008c), this switch to green electricity will affect only a minority of road freight operations. Greater use will also be made of fully electrified vehicles (or 'plug-ins'). No forecasts have yet been made of the combined effects of the biofuel and electrification trends on the carbon intensity of road freight energy usage in 2050. Embedded in the Tremove (2009) database is an assumption that a switch to biofuels will cut the average carbon content of energy consumed by trucks by 10% by 2030. Projecting this rate of conversion to biofuel blends forward to 2050 would cut their carbon content by 14% by 2050. To this figure, must be added some allowance for the hybridisation and electrification of rigids. It is assumed that these trends will double the reduction in carbon intensity to 30%.

5. CO_2 Scenarios for Road Freight Transport in 2050

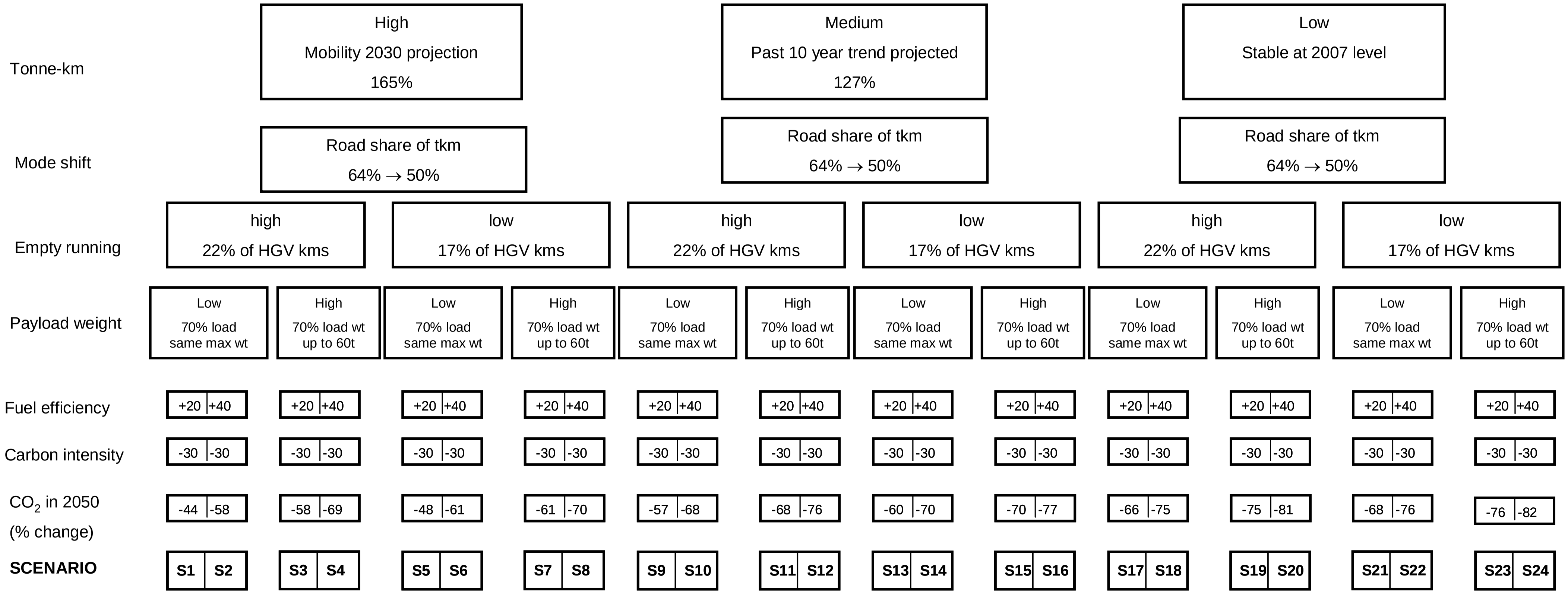
Figure 2 summarises the results of the modelling exercise and shows the reduction in CO_2 emissions from road freight transport that would be achieved across the 24 scenarios from the base year of 2007. Eight of these scenarios (S12, S16, S18, S19, S20, S22, S23 and S24) would meet the 75% reduction target (relative to 2007). Six of these eight scenarios are predicated on the total amount of freight movement in 2050 being the same as in 2007. All of them assume a 20% drop in road's share of the freight market and 30% decline in the carbon intensity of the energy used. The scenario yielding the largest carbon savings (S24) is naturally based on the most propitious set of circumstances. Other scenarios with savings above the 75% threshold vary in the balance they strike between vehicle loading and fuel efficiency. It is also worth noting that a savings in excess of 75% can still be achieved when tonne-kms grow by 27%, so long as the maximum levels of load consolidation and improved fuel efficiency are attained. The combined effect of relaxing only a few of these conditions can yield a markedly different outcome, as illustrated by the worst-case scenario (S1). Allowing road freight tonne-kms to grow at the rate predicted by the Mobility 2030 study, maintaining truck weight (and size) limits at their present level, having empty running stabilise at 22% of truck-kms and increasing fuel efficiency by 20%, rather than 40%, would result in CO_2 levels going down by 'only' 44%. This demonstrates the sensitivity of the CO_2 savings to changes in these critical parameters across the numerical ranges tested in this modelling exercise.

The analysis suggests that, at low and medium rates of tonne-km growth, most of the six 'levers' would have to be given a very strong pull to achieve the necessary reduction in CO_2 emissions by 2050. If the amount of freight movement were to grow at the rate forecast by WBCSD (2004), however, pulling them all to the maximum extent allowed in this analysis would not be enough to meet the target.

In interpreting the results of this analysis several points must be borne in mind:

1. The modelling makes no allowance for any inverse relationships between freight parameters. For example, substantial increases in the maximum weight and size of trucks and in their utilisation would improve the competitiveness of road haulage and make it much harder for alternative modes to expand their share of the freight market.

Figure 2: Carbon Reduction Scenarios for UK Road Freight Transport



2. The recent decoupling of road freight growth from economic growth in the UK, which .underpins the assumption in some scenarios that future tonne-km growth will be low or zero, has been partly due to the off-shoring of manufacturing activity and upstream supply chains to low labour cost countries (McKinnon, 2007a). The continuation of this decoupling trend will make it easier for the UK to achieve its carbon reduction targets in the freight sector, but merely displace the related carbon emissions to other parts of the world, with no net environmental gain in planetary terms.

3. No account is taken of the infrastructural changes that would be required to accommodate large modal shifts and new LHV fleets. For example, if total tonne-kms were to increase in line with the mid-range estimate and the reduction in road's share of the freight market were achieved solely by transferring goods to rail, the amount of freight movement on the rail network would increase by a factor of three. Carbon emissions associated with the development of transport infrastructure have been excluded from the calculation.

4. Applying this type of analysis to a single sector ignores the effects of the predicted decarbonisation trends on CO_2 emissions from other related sectors. Emissions in one sector may therefore be cut at the expense of increases in others. For example, around a quarter of the 82% reduction in CO_2 emissions in scenario S24 is attributable to the transfer of freight to other transport modes. Their CO_2 burden would, therefore, increase, though not in proportion to the growth in tonne-km. Rail and coastal shipping currently have average CO_2 intensities, respectively, 78% and 67% lower than that of the heaviest class of HGVs (over 38 tonnes gross weight) (McKinnon, 2007b). At present only around 10% of UK railfreight is hauled by electric locomotives. This proportion is likely to rise sharply by 2050 and by then most, if not all, the electricity will be generated with minimal carbon emissions[3]. As the hybridisation / electrification of long haul road operations will prove difficult, switching longer distance freight flows to low-carbon electrified rail services would significantly cut the carbon footprint of the UK freight transport sector as a whole.[4] To

[3] From renewal energy sources, nuclear power or fossil fuel generators equipped with carbon capture and storage.

[4] No allowance was made in the modelling for future increases in the energy efficiency and reduction in the carbon intensity of alternative freight modes.

assess the net reduction in CO_2 from this trend it would be necessary to broaden the scope of the calculation to the entire freight transport system.

A strong case can also be made for extending its scope even further to embrace other logistical activities such as warehousing and materials handling. The dramatic improvements in vehicle utilisation envisaged by 2050 would require some re-prioritising of logistical objectives. Inventory levels might have to rise and the amounts of storage space at both ends of the freight movement increase to permit greater load consolidation. These 'post-JIT' changes will carry a CO_2 penalty which would have to be factored into a decarbonisation analysis conducted at a logistical rather than transport level. By broadening the definition of the sector, more of these carbon trade-offs could be formally incorporated within the modelling.

6. Conclusions

This preliminary assessment of the potential for decarbonising the road freight sector suggests that the combination of a series of radical, but probably feasible, changes could cut CO_2 emissions by the 80% target adopted by the UK government for the economy as a whole for 2050 (relative to 1990). Of the two dozen scenarios tested the eight most optimistic would attain this level of reduction but require step changes in vehicle technology and corporate behaviour. In the space available it has not been possible to discuss the public policy interventions that will be necessary to promote these changes. Some of these measures are discussed in McKinnon (2007b and 2008). Nor has it been possible to explore in detail the complex inter-relationship between decarbonisation trends in different sectors. The analysis has, nevertheless, indicated the magnitude of the challenge confronting logistics managers as they prepare their freight transport systems for a very low carbon world.

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