Chapter 1 The Need for Sustainable Road Transport

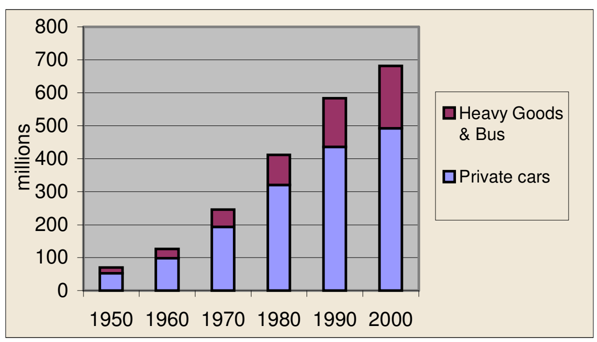
1.1 Road Transport Contexts

1.1.1 Road Vehicle Population

The global motor vehicle population is approximately 680 million vehicles[1] (Davis 2001). Levels of national vehicle registration are highly variable. Whereas China has around 13 million motor vehicles, the USA has a population of around 215 million. In the UK, the number of registered road vehicles in use is almost 29 million (DTLR 2001a).

During the last 50 years, the global vehicle population has increased by a factor of ten. Over the period 1990-1999, the average annual percentage increase in the number of vehicles was approximately 2% (Davis 2001). If this rate of increase continues, the global vehicle population could exceed 1000 million by the year 2020 (Figure 1.1).

Figure 1.1 : Global motor vehicle population



Within the UK, the last 50 years has seen an increase in the number of road vehicles by an order of magnitude. Over the last decade, the percentage increase in the car population has been approximately 2.5% per annum and heavy-duty vehicles have increased by 0.8% per year (Davis 2001). If these trends continue, the UK vehicle population could be over 40 million by 2020. Figure 1.2 shows the upward trend for the

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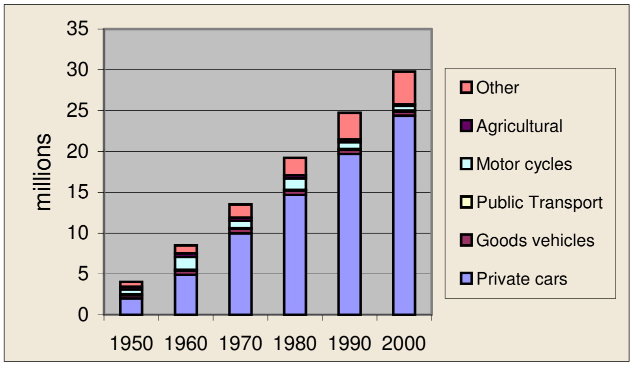
[1] All motor vehicles are included with the exception of motorcycles. In the UK and USA, they account for less than 3% of the vehicle population.

number of licensed motor vehicles on British roads. Note that of the UK vehicle stock, private cars comprise approximately 80% of road vehicles (DTLR 2001a).

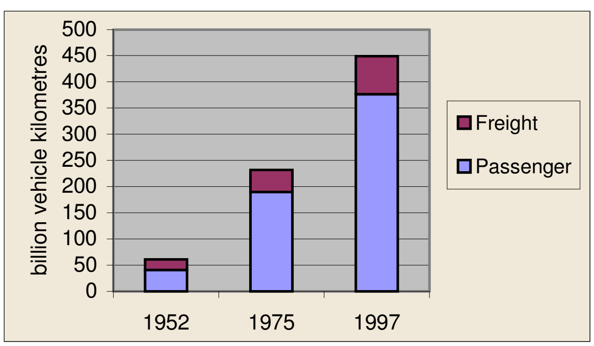
Figure 1.2 : UK motor vehicle population



1.1.2 Vehicle Kilometres Travelled

In addition to the significant increase in vehicle population, there has also been a change in the number of vehicle kilometres travelled (freight and passenger). This is due to both an increase in individual vehicle kilometrage and, for personal travel, also to a reduction in the average passenger occupancy per vehicle. Figure 1.3 shows that in the UK, over the 45 years to 1997, there has been a sevenfold increase in the number of vehicle kilometres travelled.

Figure 1.3 : UK motorised vehicle kilometres travelled



Within these overall trends, certain sectors are increasing faster than others. Since 1952, in the UK passenger sector, car and taxi kilometrage has increased by a factor of twelve and goods movements have almost trebled. However, bus traffic has remained largely unchanged and two-wheeled motor vehicle use has declined (see Table 1.1).

Table 1.1 : UK road vehicle kilometres travelled (VKT) (DETR 1999a)

Type of Traffic		1952	1975	1997	1997 index (1952=1.0)
Passenger	Cars & Taxis	30.6	181.6	367.8	12.0
	Motorcycles	6.0	5.1	4.0	0.7
	Large buses/coaches	4.2	3.2	4.9	1.2
Freight	Light vans	8.7	21.3	40.5	4.7
	Goods vehicles	11.3	20.5	31.8	2.8
All motor vehicles		60.8	231.7	448.9	7.4

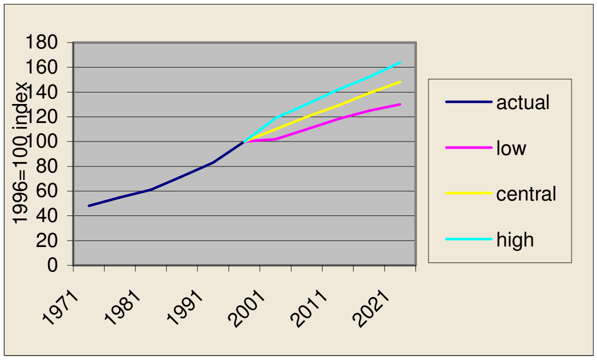
It is important to have an accurate projection of future vehicle numbers and levels of use to be able to make accurate predictions about the future impact of road transport on the environment. The National Road Traffic Forecasts, conducted in 1997 by the Department of Environment, Transport and the Regions,[2] estimated the level of road transport to 2031 (DETR 1997). These forecast the number of vehicle kilometres per year using the assumptions of the relationship between personal income, car ownership, GDP and fuel price and include the limits on growth imposed by increasing congestion.

The study predicted an increase in vehicle kilometres travelled of 57% (central scenario) from 1996 to 2031; the increase being predominantly due to a rise in private car use (39%) but including a significant increase in heavy-duty vehicle use. Figure 1.4 schematically shows these forecasts (DETR 1997).

Although the above projections are for the UK, similar trends are expected in other developed countries over the next 30-40 years (Davis 2001). Even larger growth rates may occur in developing countries on the verge, or just beginning, to industrialise. For example, many Asia-Pacific nations are about to embark on a period of industrial expansion first seen in Europe in the early twentieth century.

[2] After government reorganisation, The Department of the Environment, Transport and the Regions (DETR) was renamed the Department of Transport and Local government for the Regions (DTLR) in 2001.

Figure 1.4 : UK road traffic forecasts (vehicle kilometres travelled)



1.1.3 Conventional Road Transport Fuel Use

In 1996, global petroleum consumption was 71.5 million barrels per day (160 EJ/yr) (Davis 2001). In the UK, the 1999 UK consumption of petroleum products was 77 million tonnes, of which 72% was used by the transport sector. In energy terms, transport in 1999 used 54 million tonnes of oil equivalent (2.3 EJ/yr) which represents 32% of total UK energy consumption. This percentage has risen steadily over the past 40 years. In 1960, the proportion of energy used by transport stood at only 17%.

Nearly all UK conventional internal combustion engine (ICE) vehicles use either petrol or diesel. For vehicles over 3.5 tonnes, the fuel used is almost wholly Ultra Low Sulphur Diesel, as the diesel engine is most suited to the requirements of heavy-duty vehicles. For light-duty vehicles, the most common fuel used is Ultra Low Sulphur Petrol. As of 1998, the ratio of petrol to diesel vehicles was around 8:1. That this ratio was around 19:1 in 1990 shows an increase in the use of diesel, which has been due to the increase in the number of diesel cars (DETR 1999b). Overall, the ratio of petrol to diesel fuel use is almost 2:1 (by mass).

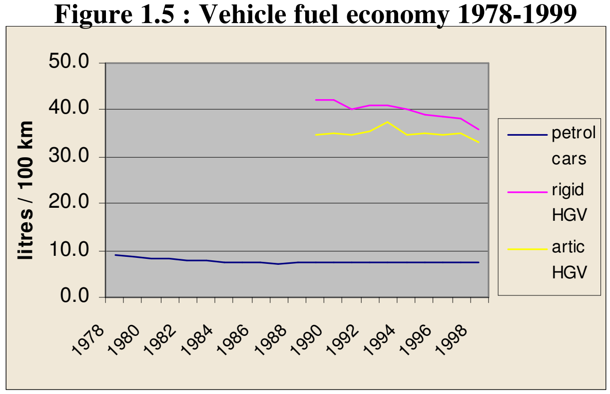
Vehicle fuel economy

For passenger petrol cars, data taken from a selection of industrialised nations shows that fuel economy is typically within the range of 7.5-11.6 litres/100 km (24-37 mpg) (Potter 2000). The lowest and highest figures are for vehicles from Italy and the USA respectively. In the UK, the 1995 average car fuel economy was about mid-way, at 9.1 litres/100 km (31 mpg).

Surprisingly, the UK figures show only a small improvement in fuel economy since 1970 when the average fuel economy (for petrol cars) was 9.6 litres/100 km (30.0 mpg). This is due to the fact that improved engine efficiency has been offset by tighter emission and safety standards and also to the increasing demand for energy intensive vehicle features such as power steering and air conditioning (DETR 1999b). However, there are very good reasons to believe that there is room for further improvement in fuel economy. In the 1990s, many major vehicle manufacturers produced prototype vehicles that were capable of around 3.0 litres/100 km (100 mpg). However, few of these vehicles have reached commercial production (one notable example is the VW Lupo 3L 1.2 TDI which has an economy of 3.0 litres/100km).

Within the heavy-duty diesel sector, fuel consumption slightly improved during the 1990s. For 'rigid' vehicles, consumption changed from 40.3 to 36.2 litres/100km (6.9 to 7.7 mpg) and for articulated trucks from 35.2 to 32.8 litres/100km (7.9-8.5 mpg) over the same period.[3] Larger 'artics' (over 33 tonnes) have shown an improvement of around 13% due to more efficient engines and improvements in aerodynamics (DETR 1999b).

Figure 1.5 : Vehicle fuel economy 1978-1999



[3] ‘Rigids’ have a lower fuel economy as they are used predominantly in urban areas whereas 'artics' are used for inter-city journeys.

1.1.4 Environmental Impacts Of Road Transportation

> *The level of motor vehicle use is considered a "source of more air pollution than any other single human activity"* (OECD 1995).

Current transportation technology and fuel use leads to environmental pollution as a result of complex physical and chemical processes. This is due to emissions produced during vehicle and fuel manufacture, production, use, recycling and disposal. In addition, there are important environmental impacts associated with road construction, road maintenance and the development of the transport and fuel infrastructure required by a road based transport system.[4]

In use, within an internal combustion engine, chemical processes take place between the hydrocarbons of the fossil fuel, the fuel additives and the gases that naturally occur in the atmosphere. The processes include complete and partial oxidation of the fuel, which produces carbon dioxide (CO_2) and carbon monoxide (CO). Nitrogen from the air is also oxidised to nitrogen oxides (NOx). Partially burnt and unburned fuel is present in the exhaust gases and forms a complex cocktail of volatile organic compounds (VOCs) together with small particles of matter (' particulates' or PM), which are especially prevalent in diesel fumes. To a lesser degree, lead (Pb)[5] is emitted with the exhaust gases and ozone (O_3) is produced by the chemical action of sunlight on VOCs.

Table 1.2 shows the extent of the impact of a single car on the immediate and global environment. The figures are based on the Life-Cycle Analysis (LCA) of a VW Golf car travelling 13,000 km per year for 10 years before being scrapped. The data is taken

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[4] Vehicle manufacture and road construction impacts have been excluded from the analysis. This is due to the fact that energy consumed during vehicle manufacture is small in comparison to lifetime energy use (Potter 2000), and that energy expended in road manufacture and repair are assumed to remain broadly constant for all vehicle technologies considered.

from the Environment and Forecasting Institute in Heidelberg (Teufel *et al.* 1993) and excludes road construction, land use and accidents. While some of the impacts listed within the table may be considered small, it should be remembered that with over 680 million vehicles on the road globally, the cumulative impact on the environment is likely to be highly significant.

Table 1.2 : LCA energy consumption and emissions for a VW Golf

Primary Energy	595 GJ	Road surface abrasion	17500 g
CO2	59.7 tonnes	Tyre abrasion	750 g
SO2	32.8 kg	Brake abrasion	150 g
NOx	89.5 kg	Lead	85.8 g
Particles	4.2 kg	Chrome	0.2 g
CO	368.1 kg	Copper	4.3 g
CxHy	62.9 kg	Nickel	1.2 g
Polluted Air	2040 million m3	Zinc	0.8 g
Benzol emissions	812.5 g	Platinum	1.3 mg
Formaldehyde	203.1 g	Crude oil into oceans	13 litres
Source : Teufel *et al.* 1993			

In the UK, although domestic and industrial sectors are also responsible for air pollution, road transport remains the predominant source for some emissions. This is the case for benzene, 1,3-butadiene, carbon monoxide and NOx. Road transport is also a significant contributor of carbon dioxide (20%) and hydrocarbon emissions (30%) (DETR 1999b). However, within urban areas, the percentage contributions due to road transport can be significantly higher. For example, although road transport is responsible for around 26% of particulates[6] on a national level, in London, road transport contributes 78% of known primary emissions (see Table 1.3).

Table 1.3 : UK emissions due to road transport

Emission	UK as a whole	London
benzene	65%	82%
1,3-butadiene	77%	97%
CO	75%	97%
NOx	48%	75%
PM_{10}	26%	78%
CO2	20%	20%
HCs	30%	60%
Source : DETR 1999b		

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[5] Leaded fuel has been phased out in the European Union (see section 1.1.5).
[6] Note that particulates with a size of 10 microns of less are known as 'PM_{10}'.

Environmental effects of emissions

Vehicle emissions are responsible for deleterious effects on local and regional air-quality and human health. There is a growing body of evidence to link many pollutants to the incidence of respiratory disease. In 1998, the Committee on the Medical Effects of Air Pollutants estimated that between 12,000 and 24,000 people die prematurely each year in the UK as a direct result of air pollution, a large proportion of which is produced by road transport. In addition, 14,000 to 24,000 hospital admissions may also be the result of poor air quality (Holgate 1998). These health impacts are due to the presence of three emissions analysed by the study. The effects of each pollutant studied was as follows; particulates (estimated to bring forward 8,100 deaths annually), sulphur dioxide (3,500) and ozone (up to 12,500 deaths). Other health effects of vehicle emissions (not included in the above study) follow from the known carcinogenic properties of VOCs and ozone both on plant and animal life, and the effects of lead on the nervous system.

Vehicle emissions have also contributed to the increasing concentration of gases that are leading to climate change (global warming). In order of significance, the principal *greenhouse gases* associated with road transport are carbon dioxide, methane and nitrous oxide (DETR 1999b; 2000a). To illustrate the scale of the impact of these emissions, as a result of human activities, the atmospheric concentration of carbon dioxide (from all sources) *"has increased by 31% since 1750. The present… concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years"* (IPCC 2001). Over the last two decades, about three-quarters of the anthropogenic emissions of carbon dioxide have been a result of burning of fossil fuels, the rest being predominantly due to land-use change (e.g. deforestation).

By enhancing the *greenhouse effect*, greenhouse gas emissions are leading to increases of the Earth's atmospheric, land and sea temperatures. During the 20th century, the global average surface temperature (the average of near surface air temperature over land, and sea surface temperature) increased by 0.6 ±0.2°C (IPCC 2001). This temperature is predicted to increase by 1.4-5.8°C by 2100 (1990 baseline). Based on palaeoclimate data, the projected rate of warming *"is very likely to be without precedent during at least the last 10,000 years".* The concomitant rises in sea levels and resulting climatic change will be of great (and as yet unknown) significance to all patterns of life on Earth.

The impacts of gaseous emissions can be categorised according to their sphere of influence. Some impacts can be considered as *local* while others are best viewed as *regional* or *global* effects. For example, the main health effects of carbon monoxide emissions from road transport are found within urban areas where the concentrations of both vehicles and people are greatest. In contrast, the impact of carbon dioxide emissions is most significant at the global scale, irrespective of the location of the emission source. This distinction is useful for the analysis of the environmental impacts of transport emissions and is used in the modelling of lifecycle emissions in later chapters. As the details of the environmental effects of each pollutant are beyond the scope of this thesis, the main impacts are summarised in Box 1.1. For a more detailed discussion of the environmental effects of road transport refer to the reports of the *Royal Commission on Environmental Pollution* and *Environmental Impacts of Road Vehicles in Use* (Houghton 1995; DETR 1999b).

Box 1.1 : Effects of emissions associated with road transport

Carbon Monoxide	**Local**	Produced during the incomplete combustion of carbon compounds such as fossil fuels, this gas is known to be deleterious to human health. In respiration it readily combines with haemoglobin in the blood thus hindering the body's abiliy to take up oxygen. It is thought therefore to cause and aggravate respiratory diseases and heart disease. Carbon monoxide also contributes to a small degree to global warming. This it does indirectly after first taking part in chemical reactions within the atmosphere. This is called *indirect radiative forcing*. One such reaction would be with oxygen forming carbon dioxide, thus contributing to a positive radiative forcing.
Nitrogen Oxides	**Local, Global**	As a result of the high temperatures occurring during combustion, nitrogen combines with oxygen from the air forming oxides of nitrogen. These gases are known to be responsible for acid deposition via the formation of nitric acid. Also nitrous oxide (N_2O) contributes directly to global warming and nitrogen dioxide (NO_2) is toxic even in small concentrations. Nitrous oxide contributed about 7% to the enhanced greenhouse effect in the 1980's.
Particulates	**Local**	Fine particles produced by incomplete combustion, the burning of lubrication oil and by the presence of impurities within the fuel are responsible for what is commonly known as 'black smoke'. Typically with a dimension of the order of 15 microns or less (<PM_{15}), they are known to be responsible for respiratory problems and are thought to be carcinogenic. In 1995, the World Health Organisation issued a report stating that there are no concentrations of airborne particulate matter (of size PM_{15} or less) that are not hazardous to human health.
Volatile Organic Compounds	**Local and Global**	VOCs consist of a number of different compounds including hydrocarbons (e.g. methane), halogenated and oxygenated organics, which are released during the production, refining, storage and combustion of fossil fuels. The largest environmental risks of VOCs are due to the presence of benzene and 1,3 butadiene, which are both carcinogens and are easily inhaled due to the volatile nature of these compounds. Other chemicals in this category are responsible for the production of ground level ozone that is toxic in low concentrations. Methane is an important greenhouse gas and is released during the drilling for oil and gas and during the combustion of petroleum products. However, in total, only about 5% of the emissions of methane are due to the production and use of fuels used for road transport. Other human enterprises such as landfill and cattle farming are more significant producers of the gas.
Carbon Dioxide	**Global**	While carbon dioxide is non-toxic, its main environmental effect is as a greenhouse gas. Since the eighteenth century, the concentrations of carbon dioxide have increased from 280 ppm to 353 ppm, an increase of nearly 26%. This has been exclusively due to human activities involving the combustion of carbon carrying fossil fuels, the use of which increased significantly during the industrial revolution. It is salutary to note that CO_2 concentrations have never previously exceeded 300 ppm during the last 160 thousand years. Since 1850, the average global temperature has increased by approximately 0.5^oC which, via thermal expansion of the oceans, has produced an increase in average sea levels is 1.8 mm per year. In 1990, the International Panel on Climate Change (IPPC) concluded that doubling the amount of CO_2 in the atmosphere would likely increase the Earth's surface temperature by between 1.5 and 4.5^oC. Carbon dioxide is assigned a direct Global Warming Potential (GWP) of 1 (unity) and provides the standard with which other greenhouse gases can be compared. Whilst having a small GWP compared to chemical such as CFCs (GWP of approximately 8000), the sheer volume of CO_2 emitted means that carbon dioxide remains the major contributor to global warming (responsible for 80% of UK greenhouse gas emissions). Each year an estimated 28,000 million tonnes of carbon dioxide are emitted due to man made emissions, 2% of which originates from human activity in the United Kingdom. In the UK, road transport is responsible for approximately 20% of the UK total.

Lead	**Local**	Lead is known to affect the mental development of young children and is known to be toxic in small quantities. Originally introduced into petroleum products, it was intended to act as a valve lubricant within a conventional combustion engine. It remains unchanged during combustion and is emitted with the exhaust gases. In the 1980s, road transport was responsible for three quarters of the lead present within the air. However, due to the introduction of unleaded petrol and the elimination of leaded fuels in Europe in 2000, since 1975, the amount of lead emitted has fallen by over 80%.
Tropospheric Ozone	**Regional**	In the stratosphere, ozone absorbs ultraviolet light, therefore reducing the number of harmful rays reaching living organisms on the Earth' s surface. However, at ground level, ozone is toxic and easily inhaled by animals of absorbed by plants. Ozone is thought responsible for aggravating respiratory problems in humans and is known to reduce crop yields. While the concentration of stratospheric ozone is being depleted by the action of CFCs and other chemicals, exhaust emissions from road vehicles are increasing the concentration of ozone at ground level. While there are a number of sources of man-made ozone, transport is known to contribute significantly to the total emissions through the action of emitted VOCs. The Expert Panel on Air Quality Standards (EPAQS) recommends that the average concentration of ozone should not exceed 50 ppb over an 8 hour period or 100 ppb over 1 hour. In the UK, these figures are regularly exceeded and ozone peaks can occur in urban and rural areas. Ground-level ozone is considered a regional rather than a local pollutant as high levels of ozone are often reported simultaneously from several regions of Europe. There is also evidence to suggest that high emissions of nitrogen oxides in urban areas are responsible for the lower levels of ozone found there; nitric oxide ' scavenges' ozone to produce nitrogen dioxide and oxygen.
Sources: Revkin 1992; Houghton 1995; DETR 1999b, Kitman 2000.		

1.1.5 Vehicle Emission And Air Quality Standards

The following section is based upon original research conducted by the candidate for the Report of the Alternative Fuels Group of the Cleaner Vehicle Task Force. The report was published in 2000 (DTI 2000).

In response to the growing scientific evidence of the adverse effects of air pollution, national and international regulations have been introduced to reduce gaseous emissions from the road transport sector.

UK Air Quality Strategy

The UK government began in July 1997 to implement the National Air Quality Strategy. The policy sets standards and objectives for eight major air pollutants and seeks to strike a balance between national and local action (see Table 1.4). The Strategy involves the following approaches:

- Demand management: reductions in transport demand where possible.
- Changing modal split: fewer vehicle km are required to fulfil same tasks.
- Optimisation: fewer environmental resources are required to perform same task.
- New technologies: employment of cleaner transport technologies (IT and vehicles).

The government's assessment is that current and planned technology, regulatory measures and fiscal policies will result in the UK air quality objectives for carbon monoxide, lead, benzene and 1,3 butadiene being met. However, it is expected that additional measures will be needed, particularly in urban areas to meet the objectives for NOx and particulates.

Table 1.4 : Summary of UK National Air Quality Standards and Objectives

Pollutant	Level	Unit	Exceedences allowed	Measuring period	Date
Nitrogen Oxides	105	ppb	18/yr	hourly mean	end 2005
	21	ppb		annual mean	end 2005
Carbon Monoxide	10	ppm		running 8 hour mean	end 2003
Benzene	5	ppb		running annual mean	end 2003
Particulates	50	µg/m3	35/yr	running 24hr rolling mean	end 2004
	40	µg/m3		annual mean	end 2004
1,3-butadiene	1	ppb		running annual mean	end 2003
Lead	0.5	µg/m3		annual mean	end 2004
Sulphur dioxide	132	ppb	24/yr	1 hour mean	end 2004
	47	ppb	3/yr	24 hour mean	end 2004
	100	ppb	35/yr	15 minute mean	end 2005
Notes : ppb - parts per billion, ppm - parts per million					
Source : UK National Air Quality Strategy, Dept. of Environment, 2000					

European fuel and vehicle emission standards

The Auto-Oil programme was set up by the European Commission in 1993 to identify the most cost-effective means of improving air quality across Europe through improvements to vehicle technology and fuel specifications. A tripartite project, it involved the Commission and European oil and motor industries. Based on Auto-Oil's findings, the Commission proposed regulation for ratification by the European Parliament and the Council of Ministers. This led to the introduction of EU Directives ('Euro 1' and 'Euro 2') which set mandatory limits for *regulated* emissions; carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HC) and particulate matter less than 10 microns in size (PM_{10}). (Refer to the Vehicle Emission Standards in Annex 1.)

Further recommendations of the Auto-Oil programme formed the basis of decisions made by the European Council of Ministers and Parliament in 1998. These set further limits for cars and light-duty vans (< 3.5 GVW) that came into effect in 2000/01 (Euro 3) with further limits planned for 2005/6 (Euro 4). Legislation has also been introduced for heavy-duty engines from 2001 (Euro 3), with more stringent limits being introduced in 2006/8 (Euro 4). The new standards for heavy-duty engines use the more realistic 'transient cycle' as opposed to the previous steady state test cycle.

In parallel with vehicle emission standards, European fuel directives were agreed which required petrol and diesel fuels to meet a new specification from 1 January 2000. This prohibited the general sale of leaded petrol from that date. More stringent standards will apply from 2005, mandating the use of ultra-low sulphur petrol and diesel (max. 50 ppm).

Carbon dioxide emission control

As a result of the Kyoto Climate Change Convention in December 1997, the UK has a legally binding greenhouse gas emission reduction target of 12.5% by 2008-12 (1990 baseline). The UK has also set a domestic target to reduce carbon dioxide emissions by 20% by 2010. Although transport is responsible for approximately 20% of emissions of CO_2 (the main greenhouse gas), there is no current legislation which limits the amount of carbon dioxide produced per km for road vehicles. However, the European Commission's target is to reduce emissions of CO_2 from new cars sold in the EU to an average of 120 g/km. This would represent a cut of over 25% of the current average. The strategy, endorsed by the Council of Ministers in 1996, seeks to achieve the target through a voluntary commitment by European vehicle manufacturers, supplemented by fiscal measures and fuel economy labelling to influence consumer demand.

In February 1999, the European Commission reached a formal (though voluntary) agreement with ACEA, the European car manufacturers' representative, to implement the following changes for passenger cars (DTI 2000):

- Bring car models to the market with CO_2 emissions of 120g/km or less by 2000.
- Use an intermediate target of 165-170g/km (average) in 2003 as the basis for monitoring progress.[7]
- Reduce average CO_2 emissions to 140g/km by 2008 for all new cars sold in the EU.
- Review in that year the potential for additional improvements with a view to moving the new car fleet average further towards 120g/km by 2012.

1.1.6 Emissions Trends For UK Road Transport

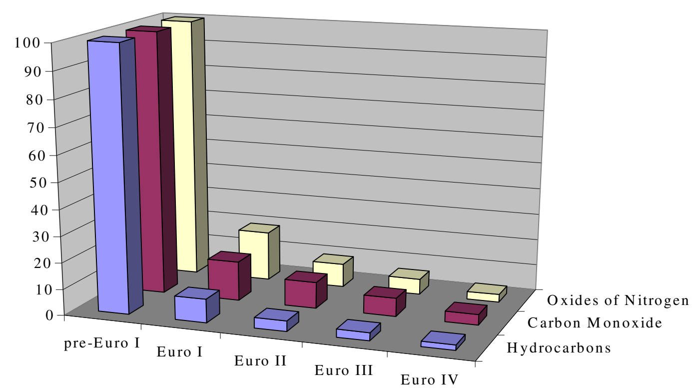
Regulated emissions

For petrol vehicles (predominantly cars), the effect of tighter Euro Standards on fuel and vehicle technology has been a significant decrease in regulated emissions per vehicle. This has been achieved in part through the use of the three-way catalytic converter that

[7] If the 2003 interim target is not reached, then the EC is likely to introduce binding legislation. Similar agreements have been agreed (in October 1999) between the EC and Japanese and Korean motor manufacturers who have given a commitment to a fleet average for passenger cars of 140 g/km by 2009.

is now mandatory on all new petrol cars. This has been highly effective in significantly reducing CO, HCs and NOx (see Figure 1.6). Diesel vehicles have also seen a significant reduction in NOx and particulate (PM_{10}) emissions as a direct result of the Euro Standards. Heavy-duty diesel vehicles now emit around half the level of particulates as they did ten years ago (DETR 1999b). These changes are in part due to the introduction of Ultra Low Sulphur Diesel that has allowed the use of cleaner diesel vehicle technologies, the development of which promises further reduction in NOx and particulates for some vehicle types.

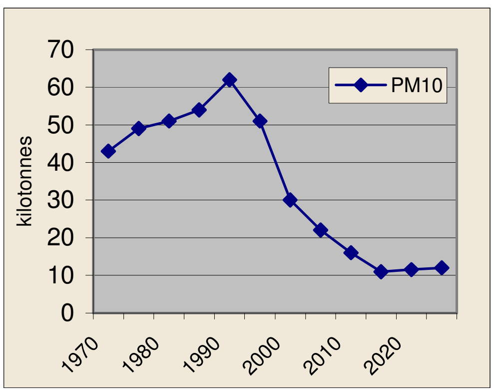
Figure 1.6 : Emission performance of petrol cars since introduction of Euro Standards (taken from EST 2001a)



Of the four regulated emissions, CO and HCs have, for most vehicle types and technologies, been controlled relatively easily over the past decade (e.g. through the use of the catalytic converter). Further reductions are expected as more stringent Euro Standards are introduced in the future (DETR 1999b). In contrast, NOx and particulates are more difficult to control and are closely associated with poor air quality. Therefore, in considering future trends for the regulated emissions, it is most informative to focus on NOx and PM_{10} emissions projections.

The DETR has made projections of NOx and PM_{10} to 2025 using the forecasts of future traffic growth and vehicle emission measurements. These forecasts, shown in Figures 1.7 and 1.8, clearly show that, in spite of increases in road traffic, between 1995 and 2015, significant reductions in NOx and PM_{10} are expected. From around 2015, these emissions are then expected to increase by a small margin as engine and fuel improvements are offset by continuing traffic growth (DETR 1999b). However, even with the introduction of more stringent Euro Standards, which lead to the reductions shown, the air quality standards for NOx and particulates will fail to be achieved in many urban areas by 2005 when the Air Quality Strategy becomes law. Modelling for year 2009 suggests that "*background concentrations [of NOx] in inner London may still exceed 21 ppb as an annual mean*" implying exceedence of allowed levels (DETR 2000c). Therefore, there will still be a need for more radical measures that may include the use of alternative fuels and vehicles (see Chapter 2).

Figure 1.7 : UK PM_{10} road transport emissions



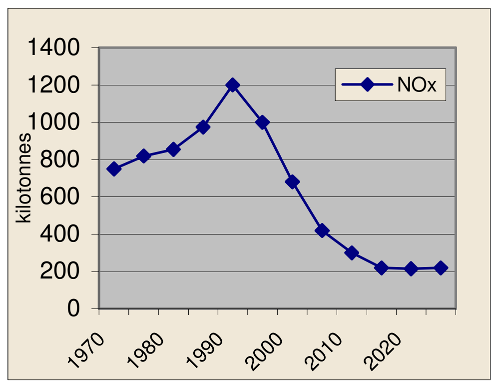


Figure 1.8 : UK NOx road transport emissions

Greenhouse gas emissions

Transport is the third largest source of UK greenhouse gas (GHG) emissions and accounts for around 20% of total emissions by end user, after the domestic and industry sectors (see Figure 1.9). This shows that in 1990, transport was responsible for emissions equivalent to 40 MtC. Of the total GHG emissions from transport, 95% are due to CO_2 emissions[8] of which around 90% are attributable to road vehicle use (see

[8] Other main greenhouse gases associated with road transport are methane and nitrous oxide (DETR 2000a).

Figures 1.10 and 1.11). Therefore, the road sector carbon dioxide accounts for around 85% of total transport GHGs.

The main three sectors contributing to carbon dioxide emissions are petrol cars (55%), heavy-duty diesels (23%) and diesel cars (7%) (DETR 2000a). These figures reflect both the CO_2 emissions for each vehicle type and the different numbers of petrol and diesel vehicles. However, as the car sector represents 63% of all road CO_2 emissions, it is a sector which will need to be made more fuel-efficient (or converted to other fuels) if CO_2 is to be reduced from road transport overall.

Figure 1.9 : UK GHG emissions by end user

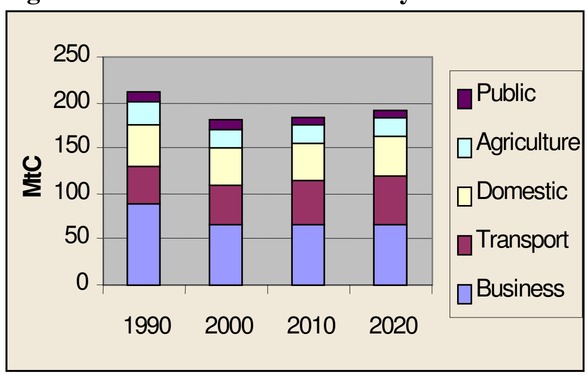
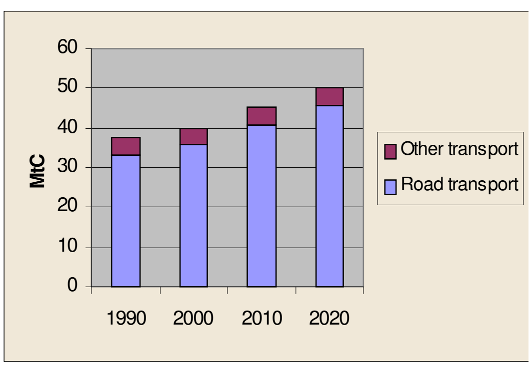


Figure 1.10 : CO_2 emissions from UK transport



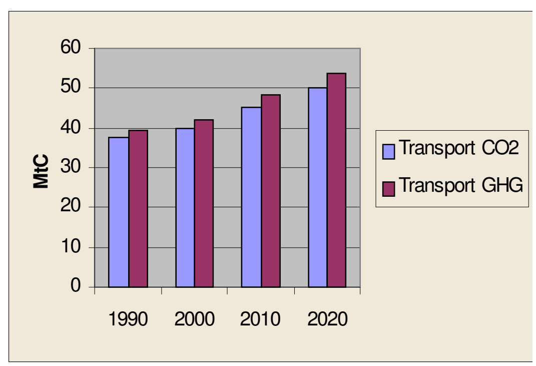


Figure 1.11 : GHG emissions from UK transport

The transport sector is the fastest growing source of GHGs with emissions increasing by 6% per annum between 1990 and 1997. The business as usual (BAU) projections[9] are for a 15% increase in GHGs from transport by 2010 (DETR 2000a). Figures 1.9 and 1.10 show the increase in GHG and CO_2 emissions from road transport over the coming two decades. This is consistent with the predicted increase in road traffic, together with the limited improvements in vehicle fuel-efficiency as discussed in sections 1.1.2 and 1.1.3. If the voluntary agreements with motor manufacturers materialise, reduced emissions from new cars would only cut 2010 road transport emissions of CO_2 by a small margin (of around 2 MtC).

1.2 Sustainable Road Transport

1.2.1 Technology And Sustainable Development

Although the concept of 'sustainability' has become a central tenet of much late twentieth and early twenty-first century political thinking, there exists no single definition for the term (Weaver *et al.* 2000). Even if it did, it is unlikely that it would satisfy all applications of the concept. However, for the purposes of monitoring the levels and severity of current environmental impacts, it would be informative to formulate an operational definition. This thesis takes as a starting point one of the most widely known descriptions of sustainability, the quote from the Bruntland Commission. This states that sustainable development "*meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED 1987). At the very least, this provides a lay-description and forms the basis for a more rigorous specification of the term ‘sustainability’. In practice, sustainable development is considered as having three strands, often referred to as the 'triple bottom line'. These are sustainable *environmental, social* and *economic* development. These strands together

[9] No policies from White Paper on Integrated Transport, Transport Bill or EU CO_2 agreements with car manufacturers.

are considered to form an interrelated space within which sustainable development can be assessed and (hopefully) implemented.

One study has operationalised the concept of sustainable *environmental* development in relation to the role and development of technology. This was conducted by Weterings and Opschoor at the Advisory Council for Research on Nature and the Environment in the Netherlands (RMNO) (reported in Weaver *et al.* 2000). The study built upon the idea of there being limits to the environmental carrying capacity of the biosphere and introduced the concept of *eco-capacity*. This attribute was given the three dimensions of *pollution,* the release of substances into the environment in quantities exceeding the release of natural cycles*, depletion,* the consumption of non-renewable resources and *encroachment,* the removal/deposition of substances within the bio-sphere at rates which exceed their replenishment/restoration.

Other analytical tools designed to support sustainable development have adopted these three dimensions. One example is The Natural Step Framework, which is a *"science and systems-based approach to organizational planning for sustainability… [that]…provides a practical set of design criteria that can be used to direct social, environmental, and economic actions"* (Natural Step 2002). The framework advocates organisational change toward systems that satisfy four system conditions. These are that the natural world is not subject to systematically increasing: (1) concentrations of substances extracted from the Earth' s crust; (2) concentrations of substances produced by society; (3) degradation by physical means; and (4) in that society, human needs are met worldwide.

The objective of the RMNO research was to ascertain the current status of a core set of resources with a view to quantifying what levels of human activity could be considered sustainable. Though this considered social development, it primarily focused on the human impacts in relation to the environment. The specific aim was to quantify the limits of environmental sustainability. The study proceeded using the following assumptions:

- The Earth's eco-capacity is finite (limited natural resources).
- 'Business as usual' scenario defined as the continuance of existing demographic, economic, social, technological and policy trends.
- Three general sustainability dimension criteria:
  (a) Depletion - there should be no absolute exhaustion.
  (b) Pollution - there should be no accumulation of polluting substances or any lasting effects for coming generations.
  (c) Encroachment - the rates of loss must not exceed rates of restoration or replenishment by natural or artificial means.

In order to quantify the depletion criteria, the study collated quantitative evidence of the economically recoverable stock of non-renewable resources for a set of indicative fossil fuels and metals. The assumptions included that non-renewable stocks should remain at, or be brought up to, a level sufficient to allow (at least) a further 50 years' use at prevailing rates of consumption. For renewable resources, the quantitative reference of the study was the rate of natural regeneration and the assumption that they should not be consumed at more than 20% of regeneration rates. For the pollution and encroachment criteria, the evidence used was collected from studies of natural processes and norms.

The study compared the sustainable levels of eco-capacity with the projected level of demand in 2040. It modelled two different population scenarios. The 'high' forecast assumed that the levels of population increase remain at current rates (leading to a projected human population of 12.7 billion in 2040). The 'low' scenario forecast changes in population growth from current levels of 0.6% and 2% in Northern and Southern hemispheres respectively to zero growth and 1.0% beyond 2025 (leading to a projected population of 9.4 billion in 2040). (Note that more recent research by the United Nations has revised these projections down. The '2000 Revision' estimates that the world's population will be in the range of approximately 7.8 to 9.8 billion by 2040 (UN 2001). Although these projections are somewhat different to those used by the Dutch study, the confidence limits of the two studies overlap. Therefore, this thesis takes the position that the findings of the RMNO study can be taken as broadly true.)

In relation to the eco-capacity limits for the use of fossil fuels, the study found that:

- Current fossil fuels use can continue at prevailing rates for around 100 years.
- Current natural gas use can continue at prevailing rates for around 75 years.
- Current oil use can continue at prevailing rates for around 50 years.

Given the forecast increases in demand, the study concluded that, for fossil fuels to be used sustainably (according to the 50-year criterion), oil, gas and coal use would have to reduce by 85%, 70% and 20% respectively (see Table 1.5).

Quantitative estimates were also made for the eco-capacity limits of global carbon dioxide emissions. The estimates were made using the IPCC guidelines on the maximum permissible rate of temperature increase of 0.1^{o}C per decade and an ultimate temperature ceiling of a 2^{o}C increase. The study adopted the findings of previous studies regarding the maximum sustainable levels of carbon release over the next century. This is estimated at 2.6 GtC/yr, which compares with a BAU scenario that predicts emissions of 13 GtC/yr by 2040. Therefore, the RMNO study concluded that by 2040, global carbon emissions would have to reduce by 80% to achieve a sustainable level. A sub-sample of the results from the study are shown in Table 1.5. Data most relevant to the conventional transport sector is shown in bold.

What is clear from the results of the study is that, as of 2001, the eco-capacity is already overstretched. If the business as usual scenario continues for another 50 years, global eco-capacity will exceed supply by 2-20 times. Within the developed world where resource use and pollution are greatest, the exceedence will be by a factor of 10-50 (Weaver *et al.* 2000). If this is to be avoided, then depletion, pollution and encroachment parameters will have to be returned to levels within the eco-capacity limits. **This thesis takes the position that, for the transport sector, this will include (at the very least) that oil use and carbon emissions are reduced by 85% and 80% respectively.**[10]

Table 1.5 : Projected versus sustainable claims on eco-capacity

	Indicator	Sustainable Level	Expected Level (2040)	Reduction Required	Scale
Depletion	**Oil**	**50-year criterion**	**Stock exhausted**	**85%**	**Global**
	Gas	50-year criterion	Stock exhausted	70%	Global
	Coal	50-year criterion	Stock exhausted	20%	Global
	Aluminium	50-year criterion	Stock >50 years	none	Global
	Copper	50-year criterion	Stock exhausted	80%	Global
Pollution	**Carbon emissions**	**2.6 GtC per annum**	**13 GtC per annum**	**80%**	**Global**
	Acid deposition	400 acid-equiv/ha/yr	2400-3600 acid-equiv/ha/yr	85%	Continental
	Cadmium	2 tonnes per annum	50 tonnes per annum	95%	National
	Copper	70 tonnes per annum	830 tonnes per annum	95%	National
	Lead	58 tonnes per annum	700 tonnes per annum	95%	National
	Zinc	215 tonnes per annum	5190 tonnes per annum	95%	National
	Note: Figures account for predicted increases in demand. Source: Adapted from Weaver *et al.* 2000				

Box 1.2 : Future supply of oil

In 2000, approximately 75% of crude oil processed in the UK originated in the continental shelf (predominantly North Sea), the rest being of Middle Eastern origin. The Middle East has approximately 64% of the worlds remaining oil reserves compared to the 8% of North America with 2% being located in Europe. Dividing the remaining reserves by today' s consumption gives an indication as to how long these reserves will last. This suggests that there is enough oil to meet the world's current demands for at least 40-50 years (Haugen 2000). UK oil reserves are estimated to have a life expectancy of around 20 years (ONS 2000).

These estimates of oil reserves may be an underestimate as new reserves are continuing to be discovered, the discovery rate being approximately equal to the amount consumed each year. In addition, the amount of oil that can be extracted from reservoirs is increasing and new technology is enabling profits to be made from reservoirs that were previously considered economically unattractive. However, recently discovered reserves have tended to consist of a larger number of smaller fields. An example is the UK shelf where, in 1985, some 5% of the oil production came from small fields with reserves of up to 100 million barrels. Today, that share is in excess of 20% (Haugen 2000).

As oil production is likely to decrease by 2050 (if not before), the conventional petrol and diesel ICE regime is likely to be challenged by 2050 due to resource limitations in addition to the pollution implications for eco-capacity. Alternatives may have to be found well before 2050 if industry is to have time to retool and install new fuel infrastructure.

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[10] Note that fuel use and carbon emissions are closely correlated in the existing petrol/diesel ICE regime.

1.2.2 Non-Sustainability Of Conventional Road Transport

Applying the results of the RMNO study to road transport, a sustainable global transport system would require that the rate of oil utilisation (depletion) would have to reduce by 85% and the global greenhouse gas emissions (pollution) would have to reduce by 80%. These targets are for 2040 and are compared to 1990 levels. This position is given weight by the Royal Commission's recommendation to cut "*carbon dioxide from surface transport in 2020 to no more than 80% of the 1990 level*" (Houghton 1995). However, as was shown in Section 1.1.6, carbon dioxide emissions from the transport sector are predicted to *increase* over the next 2-3 decades. Therefore, from the point of view of greenhouse gas emissions, road transport is currently highly un-sustainable and set to remain so if business as usual policies and technologies are continued.

In developing greenhouse gas reduction strategies, the UK government aims to develop "*a balanced approach, with all sectors playing their part*" (DETR 2000a). This implies that to achieve sustainability by 2040, the transport sector would have to adhere to the ambitious reductions indicated. However, using existing policies and technologies, it remains unclear how these significant cuts can be achieved.

Since the election of New Labour in 1997, there has been no shortage of policy directives aimed at reducing congestion and the environmental impact of road transport. These include The Road Traffic Reduction Act (1998), White Paper on Integrated Transport (1998), setting up of the Commission for Integrated Transport, Transport Bill, Transport 10-Year Plan (2000) and, at a regional level, the introduction of Local Transport Plans (2000). These programmes recommend a mix of measures to reduce transport demand by improving fuel-efficiency, introducing cleaner vehicles, influencing passenger behaviour and changing modes used by freight. The strategic measures proposed include changes in transport taxation, introduction of local authority regulations and powers, and the introduction of more stringent EU legislation and voluntary agreements. Specific policies include, graduation of Vehicle Excise Duty (VED) (according to CO_2 emissions), reform of company car taxation, road user charging, workplace parking levies, a fuel-economy vehicle labelling scheme and the voluntary agreement between the EC and ACEA to reduce average CO_2 emissions from new cars by at least 25% by 2008 (see section 1.1.5).

To quantify how the implementation of these policies may reduce the environmental impact of the transport sector, the UK government has made detailed estimates of the impact of a number of policies. In particular, in its Climate Change Draft UK Programme, the DETR has estimated the scale of greenhouse gas reductions of a selection of policy scenarios (DETR 2000a). These estimate that greenhouse gas emissions could be reduced by up to 9.8 MtC as compared to business as usual projections (see Table 1.6). This compares with a business-as-usual projection of around 48 MtC in 2010 (see Figure 1.11).

Table 1.6 : Effect of policy instruments on GHG emissions from UK transport sector

Policy measures	Predicted GHG emission reduction by 2010
• Increases in fuel duties between 1996-1999	1.0 – 2.5 MtC
• Low to high intensity implementation of Integrated Transport White Paper measures	0.6 – 3.3 MtC (England only)
• Graduation of VED (road tax) • Agreement between EC and ACEA to reduce av. CO2 emissions from new cars by at least 25% by 2008 • Reform of company car taxation	4.0 MtC
Source : Climate Change Draft UK Programme (DETR 2000a)	

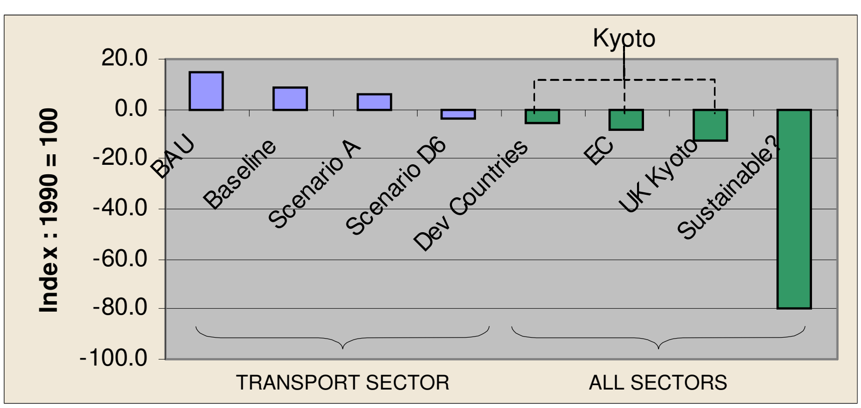
The UK Government has also estimated the impact on transport CO_2 emissions under a number of detailed scenarios developed within the document entitled *Tackling Congestion and Pollution* (DETR 2000b). Each of these makes an estimate for CO_2 emission by 2010 as compared to a 1990 baseline. The eleven scenarios range from the least intensive ' Baseline' to the most intensive ' D6' , details of which are shown in Table 1.7. The scenarios assume the implementation of sub-sets of policy measures taken from the White Paper *A New Deal for Transport* (DETR 1998) and other policy programmes (see above).

Table 1.7 : Effect of policy scenarios on UK GHG emissions from UK transport sector

Baseline Scenario	Scenario D6 - Most Intensive
• Fuel duty escalator • Graduation of VED • EU voluntary agreement to reduce CO2 emissions from new cars • More stringent EU emissions standards • Targeted increases to road network capacity	• Implementation in ALL urban areas of higher levels of road charging and/or workplace parking levy • Improved public transport, cycling and walking facilities • Increases to the capacity AND charging on most congested inter-urban roads • Increases in real fuel duty – 19% in total after 1999 • Much higher levels of rail investment AND high impact from passenger rail, land use planning and sustainable distribution policies
Source : Tackling Congestion and Pollution (DETR 2000b)	

If it is assumed that the proportion of CO_2 within total GHGs from transport remains constant over the next decade, estimates of the impact of each scenario can be made for the total GHGs (in 2010) and compared with both the business as usual case (BAU) and other reduction targets. In particular, a comparison can be made between the projected scenario outcomes and the targets specified by Kyoto agreements and the reductions required to return the GHG emissions to within the Earth's eco-capacity limits (see Figure 1.12). Even with the most intensive (and probably politically unpopular) policies (e.g. 'D6'), the GHG emission reduction is only around 5% of the reduction required to achieve a sustainable road transport system (as previously defined). Therefore, these policy scenarios are not sufficient to implement sustainable road transport in the UK. Additional measures will need to be considered. The next section investigates what other strategies are available.

Figure 1.12 : Effect of policy scenarios on UK transport GHG emissions (2010)



1.2.3 Strategies For Change: 'Technical-Fix' Versus Modal-Shift

To achieve sustainability, there are three approaches to reducing the environmental impact of any sector to levels at or within the limits demarcated by eco-capacity considerations. These are:

1. Influence the scale of demand for final goals and services - *demand management.*
2. Increase the available eco-capacity - *environmental management.*
3. Increase the efficiency with which eco-capacity is utilised - *resource management.*

All three strategies can be implemented by both behavioural and/or technological change. Demand management may be influenced to a larger degree by changes in behaviour (e.g. modal-shift) than technology (e.g. information systems), whereas resources management is likely to be more effected by the use of new technologies (e.g. cleaner vehicles) than changes in driver behaviour (e.g. more efficient driving). Environmental management practices can involve both technology (e.g. CO_2 burial) and behavioural change (e.g. carbon sequestration).

The methods that may eventually provide a sustainable transport system are likely to involve social, political and economic factors. Policy responses will involve a mix of measures that aim to effect a modal shift to less damaging forms of transport (e.g. bus, rail and cycle) and reduce the need for travel. However, as was shown in Section 1.2.2, conventional demand management practices, even in their most intensive implementation, are unlikely to return greenhouse gas emissions from UK road transport to sustainable levels.

Therefore, to achieve sustainability within this sector (according to the RMNO criteria), measures will have to include one of more of the following:

- More intensive *demand management* strategies than considered by DETR in 2000.
- New *environmental management* strategies.

- New *resource management* strategies already considered in the UK, but not included in the DETR Tackling Congestion and Pollution scenario D6 (see above).

The demand measures which form the majority of Scenario D6 (see Table 1.7) would be considered by most UK politicians and commentators to be impossible to implement, particularly following the September 2000 protests over levels of fuel duty on petrol and diesel fuels. Therefore, the prospect of implementing highly intensive demand management strategies seems unlikely in the UK before 2005 at the earliest.

The introduction of environmental management strategies is gaining some acceptance within the UK and elsewhere as an effective measure to combat global warming. This includes the use of tree planting programmes for carbon sequestration, an approach that is considered within the Climate Change Draft UK Programme (DETR 2000a). However, the potential impact of this measure is limited by land availability the UK. The DETR estimate that a 0.6 MtC reduction could be achieved by 2010 (1990 baseline).

Therefore, although demand and environmental management measures will form a *necessary* part of the overall strategy to reduce UK road transport greenhouse gas emissions to levels indicated by eco-capacity limits, they are not *sufficient* to achieve the reductions required. Therefore, this thesis concludes that resource management strategies must also be considered; including the introduction of more efficient conventional and cleaner vehicle technologies.

This strategic approach is supported by the 1998 White Paper which identifies the need for "*improvements in fuel and vehicle technology...[which] will make a significant contribution to achieving…targets for improving air quality and reducing greenhouse gases*" (DETR 1998) and includes:

- The introduction of cleaner fuels which reduce emissions on a per kilometre basis.
- The introduction of cleaner, more efficient vehicle technologies through the incremental improvement of conventional vehicles, the addition of emission reduction technology and/or the introduction of cleaner vehicles.

Therefore, increasing attention is now being focused on the introduction of 'cleaner fuelled vehicles' (also known as 'alternatively fuelled vehicles') that have the *potential* to reduce local and global emissions associated with road transportation. Options include natural gas vehicles, biofuels, liquefied petroleum gas and several types of electric vehicles for public transportation, fleet and private use. Indeed, the UK government has already agreed to *'improve the environmental performance of vehicles'* and to *'explore the role for new technologies'* (Houghton 1995). These options (and their potential to reduce emissions) will be discussed in detail in Chapter 2.

Improving fuel quality alone can reduce vehicle emissions. Although, cleaner fuels have a smaller effect on emissions than do new vehicle technologies, cleaner conventional fuels do offer the prospect of improving emissions from new and old vehicles alike whereas, in general, advances in vehicle technologies improve only new vehicles. As new vehicles make up only around 10% of the UK fleet, it can take several years to maximise the potential of technological improvements. However, in the long-term, cleaner fuels need to be combined with the introduction of new vehicle technologies to maximise potential emissions reductions. In fact, the use of new technologies (e.g. exhaust after-treatment) is often dependent on the availability of cleaner products (e.g. ultra low sulphur fuels) (DTI 2000).

1.2.4 Definition And Criteria Of Sustainable Road Transport

Returning to the issue of sustainability, it is now possible to develop the previous discussion (section 1.2.1) to consider what definitions and criteria for sustainable transport are appropriate for this thesis. The OECD defines sustainable transport as:

> *"Transport that does not endanger public health and ecosystems and meets needs for access to people, goods and services consistent with the rate of use of renewable resources at below the regeneration rate, and the use of non-renewable resources at below their rate of renewable substitutes"* (OECD 1995).

If the long-term aim is to achieve environmental sustainability in all sectors, then we need to identify parameters for sustainable methods of motorised mobility.[11] Given the multitude of environmental emissions (see Table 1.2) as well as the complex social and economic impacts of road transport, it would be beyond the scope of this thesis to identify the sustainable parameters for every impact. Therefore, for the purposes of this thesis, a limited number of indicators of environmental sustainability have been chosen.[12]

Consideration of the most informative environmental sustainability indicators must include reference to the main deleterious effect of transport, which include the impacts on climate change and local air quality. The significance of these two issues can be evidenced by the importance given to these issues by international agreements such as the Kyoto greenhouse gas reduction programme and also by the UK Air Quality Strategy targets. This approach is also consistent with that of the Royal Commission on

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[11] This thesis focuses on the introduction of sustainable motorised road transport. However, it notes that non-motorised sustainable modes already exist (e.g. walking and cycling).

[12] Relevant social and economic issues relating to sustainability will be referred to and discussed where necessary during the thesis.

Environmental Pollution (Houghton 1995) which has outlined eight objectives for a sustainable transport *policy*, including:

- Achieve *air quality* standards that prevent damage to human health and the environment.
- Reduce *carbon dioxide* emissions from transport.

Therefore, for the purposes of this thesis, two transport emissions are chosen to be indicative of the level of environmental sustainability, one indicating the global impact on climate (*greenhouse gas emissions*) and the other to indicate the local effects upon air quality (*regulated vehicle emissions*). For each of these indicators, an estimate is made of the percentage reduction (from 1990 levels) that would be required to return road transport emissions to the eco-capacity limits identified in section 1.2.1.

To quantify the reductions required for greenhouse gas emissions, this thesis uses the findings of the RMNO study (described above), which showed the need for greenhouse gas emissions to be reduced by 80% of current levels if sustainability (as previously defined) is to be achieved. Given that UK demand strategies can deliver up to 5% reductions by 2010 (1990 baseline), a further 75% may be required from improvement in technology. **Therefore, for the purposes of this thesis, it is assumed that a reduction in greenhouse gas emissions of 75% (1990 baseline) will be required from improvements in technology to achieve the eco-capacity limit for road transport.**

For local environmental impact, in principle, any one of the four regulated emissions could be used as an indicator. However, NOx and PMs are associated more strongly with negative health impacts than are CO and HCs. Furthermore, the latter two are more easily controlled by exhaust emission reduction systems (e.g. catalytic converters). Other considerations are that NOx is associated with both petrol and diesel operation whereas, PM_{10} emissions from petrol vehicles are almost negligible. Given that NOx and particulates are often correlated, it makes most sense to use NOx as the indicator of (all) vehicles on local air quality. This is also the position taken by the PowerShift programme that awards subsidies for cleaner vehicles based on improved NOx performance (EST 2000).

To quantify what NOx reduction would be required to achieve eco-capacity, the projections for UK road transport emissions for 2010 have been used (see section 1.1.6). Given that existing policies together with forthcoming EU standards such as Euro 4 will not be sufficient to attain UK air quality standards for NOx in many urban areas in 2009, emissions will have to be further reduced. Sustainable NOx emissions will need to be substantially lower than the maximum Euro 4 standard, and lower than the emissions of conventional vehicles, all of which will be well within Euro 4 limits from 2006. **Therefore, for the purposes of this thesis, it is assumed that a reduction in NOx emissions of 75% (petrol Euro 4 baseline)[13] will be required to achieve the eco-capacity limit for road transport.**

Table 1.8 summarises the sustainability targets adopted by this thesis. These *lifecycle* targets will be quantified in Chapter 3 using established techniques of lifecycle analysis.

Table 1.8 : Summary of transport sustainability targets used within the thesis

Scale	Environmental sustainability indicator	Reduction to achieve eco-capacity limit	Level of analysis
Global	Greenhouse gases (GHG): carbon dioxide, nitrous oxide, methane	75% reduction (1990 baseline)	Lifecycle
Local	Nitrogen Oxides (NOx)	75% reduction (Petrol Euro 4 baseline)	Lifecycle

[13] Note that the petrol Euro 4 standard is 0.08 gms/km. This is significantly lower than the diesel Euro 4 standard of 0.25 gms/km. The petrol limit is used due to the prevalence of petrol over diesel cars. Although Euro 4 is a *vehicle* emission standard, this thesis will use it to inform the NOx eco-capacity limit on a *lifecycle* basis (see Chapter 3 for full analysis).