

Open Research Online

The Open University's repository of research publications and other research outputs

A Strategy For Reducing Emissions Of Greenhouse Gases From Personal Travel In Britain

Thesis

How to cite:

Hughes, Peter Samuel (1992). A Strategy For Reducing Emissions Of Greenhouse Gases From Personal Travel In Britain. PhD thesis The Open University.

For guidance on citations see [FAQs](#).

© 1992 The Author

Version: Version of Record

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's [data policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

DX 172040

Energy and Environment Research Unit

Faculty of Technology

**A Strategy for Reducing Emissions of
Greenhouse Gases from Personal Travel in Britain**

A thesis submitted to the Open University
in candidacy for the degree of Doctor of Philosophy

by
Peter Samuel Hughes BSc

August 1992

Abstract

The presence of 'greenhouse gases' in the atmosphere has a warming effect on the biosphere, making the world habitable for life. Human activities, particularly energy use and deforestation, are increasing the concentration of these gases, and in particular carbon dioxide (CO₂). Many climatologists believe that the global temperature is beginning to rise as a result. The Intergovernmental Panel on Climate Change (IPCC) has recommended that emissions of CO₂ be cut by 60 per cent in order to stabilise the atmospheric concentration of this gas and to minimise the resulting disruption to the world's climate.

Transport is currently Britain's fastest growing source of carbon dioxide, the principal anthropogenic greenhouse gas. An assessment is made of the relative contributions to CO₂ emissions of different forms of travel, and trends in energy use are surveyed. Emissions of CO₂ from 'secondary' sources, such as vehicle production, are also examined.

A computer model called SPACE is described, which was developed in order to assess CO₂ emissions under different policy scenarios up to the year 2025. A 'business as usual' scenario predicts that emissions will rise substantially, mainly as a result of an ongoing rise in road traffic. This contrasts with the Government's stated aim of stabilising emissions of CO₂ at the 1990 level by 2000.

A modification of this scenario, in which technological improvements to vehicles are vigorously applied, shows a reduced growth in emissions. A third scenario then examines the effect of a combination of technological and demand management policies, and demonstrates a significant reduction in emissions. Scenario 3 adopts what are seen as fairly modest policy measures, making use of their synergistic effect. The main justification for this 'non-radical' approach is public and political acceptability. It is, however, recognised that most of the policy measures could be applied more vigorously if required.

If it is assumed that transport is allotted a less stringent target than other energy-consuming sectors, the reduction in emissions projected in Scenario 3 is consistent with the IPCC goal of atmospheric CO₂ stabilisation.

Data sets compiled as part of the SPACE model can be made available on request.

CONTENTS

	Page
Introduction	1
Chapter One Global warming and climatic change	5
1.1 The issue of global warming	7
1.2 The greenhouse theory	7
1.3 Greenhouse gases	8
1.4 Historical trends in greenhouse gas concentrations	12
1.5 Climatic change	12
1.6 Effects of global warming	14
1.7 Future greenhouse emissions	17
1.8 Summary	22
Chapter Two The nature of greenhouse emissions from personal travel	23
2.1 Defining a transport system	25
2.2 Transport's share of CO ₂ emissions	28
2.3 The growth of energy use in transport	30
2.4 The wider view: non-operational energy demand in transport	41
2.5 Energy use and greenhouse emissions	45

Chapter Three	Aspects of fuel consumption in motorised travel	51
3.1	The influence of fuel consumption on greenhouse emissions	53
3.2	Fuel economy in private cars	54
3.3	Fuel economy in buses and coaches	68
3.4	Fuel economy in rail vehicles	73
3.5	Fuel economy in aircraft	78
3.6	Summary	81
Chapter Four	'Business as usual' carbon dioxide emissions from personal travel	83
4.1	The need for a model	85
4.2	The scenario approach: SPACE	85
4.3	Establishing a baseline: 'Business as Usual'	89
4.4	Population and car ownership	89
4.5	Transport demand	92
4.6	Energy consumption	100
4.7	Results of Scenario 1	105
Chapter Five	Measures for reducing carbon dioxide emissions	107
5.1	The need for policy changes	109
5.2	Approaches to controlling greenhouse emissions from transport	110
5.3	Measures to promote fuel economy	116
5.4	Measures to promote alternative fuels	126
5.5	Measures to promote modified travel patterns	144

5.6	Timescales of policy measures	162
5.7	Public acceptance of policy measures	163
5.8	Deployment of policy measures	164
Chapter Six	Scenario 2: Business as usual plus ‘technical fixes’	169
6.1	The use of ‘technical fixes’	171
6.2	The effect on the car stock	176
6.3	Results of Scenario 2	182
Chapter Seven	Scenario 3: Atmospheric stabilisation	185
7.1	The need for a more stringent target	187
7.2	Policy measures for atmospheric stabilisation	189
7.3	Assessment of policy measures	190
7.4	Constructing a stabilisation scenario	205
Chapter Eight	Conclusions	207
8.1	Principal findings	209
8.2	Implications for an overall CO ₂ reduction strategy	210
8.3	Comparison with the Netherlands National Transport Plan	211
8.4	Non-operational emissions of CO ₂	212
8.5	Beyond 2025	213
8.6	Which way now?	213
8.7	A ‘do nothing’ world?	215

References	217
Appendices	229

LIST OF TABLES

1.1	Summary of key greenhouse gases produced by human activities	10
1.2	The 20 largest contributors to greenhouse forcing in 1988	11
1.3	National responses to global warming	19
1.4	Cuts in emissions needed for a stabilisation of greenhouse gases at present atmospheric levels	20
2.1	Total energy use from UK transport demand	26
2.2	Energy losses in the production of transport fuels	28
2.3	Bus and coach population, 1986	32
2.4	Journeys and travel distance per person, 1965 and 1985	34
2.5	Energy intensity measures for various manufacturing industries in 1979	42
2.6	Energy use for different purposes according to travel mode	42
2.7	Energy consumption for constructing and maintaining road and rail infrastructure	44
2.8	Transport's emission of regulated pollutants in 1989	47
2.9	EC limit values for regulated pollutants	48
3.1	Average fuel economy of different engine sizes, 1986	60
3.2	Materials used in the Austin Metro	61
3.3	Public service vehicle fuel consumption	68
3.4	Specific energy consumption of buses and coaches (1986)	69
3.5	Primary energy consumption of rail stock in Britain	74
4.1	Government forecast of Great Britain's population up to 2025 (million)	90
4.2	Distribution of population according to household car ownership in Scenario 1.	91
4.3	Population trends projected in Scenario 1	92

4.4	Summary of the 1989 Road Traffic Forecasts	93
4.5	Assumed car occupancies for Scenario 1 up to 2025 (persons per car)	94
4.6	Bus and coach travel forecasts in Scenario 1	95
4.7	British Rail forecasts of passenger traffic to 1994/95	96
4.8	Rail traffic growth assumed in Scenario 1	96
4.9	Average rail occupancies, 1979-89 (persons per train)	97
4.10	Average rail occupancies in Scenario 1 (persons per train)	98
4.11	Growth in domestic air traffic projected in Scenario 1	98
4.12	Growth in motorcycle traffic in Scenario 1	99
4.13	Walking and cycling projections in Scenario 1	100
4.14	Fuel economy values assumed in Scenario 1 (l/100km)	102
4.15	Fuel economy projections for buses and coaches in Scenario 1	103
4.16	Traffic distribution and power supply for the rail sector in Scenario 1	104
4.17	Projected energy consumption for air travel in Scenario 1	104
4.18	Projected structure of the electricity supply industry	105
5.1	Taxation of passenger vehicles under the Ontario programme	123
5.2	Property tax payable on cars in Italy	124
5.3	Annual licence fees for cars in the Isle of Man	124
5.4	Relative greenhouse emissions per kilometre of different energy sources relative to petrol engines in the USA	140
5.5	Cost estimates for alternative fuel options in 2010	141
5.6	Policy measures for use in controlling CO ₂ emissions	165
5.7	Areas of influence for each of the policy measures	166

6.1	Illustrative example of a rebate/surcharge system for company car taxation	173
6.2	Illustrative example of a feebate scheme for car sales in Britain	174
6.3	Average and 'benchmark' fuel economy, 1986 (l/100km)	178
6.4	Fuel economy improvements assumed in Scenario 2 (l/100km)	179
7.1	Elasticity of public transport demand with respect to fares	198
7.2	Travel modes of commuters in southern California	200

LIST OF FIGURES

1.1	The carbon cycle	8
1.2	Atmospheric concentration of greenhouse gases since 1750	13
1.3	Global average temperature since 900 AD	14
1.4	Impact on atmospheric CO ₂ concentrations of various reduction strategies	18
2.1	UK CO ₂ emissions by end-use in 1989	29
2.2	CO ₂ emissions by different transport modes, 1990	29
2.3	Energy consumption by final user in the UK, 1960 and 1990 (heat supplied basis)	31
2.4	Rail passenger traffic in Britain, 1990	33
2.5	Passenger transport by mode, 1952 to 1990	35
2.6	Energy consumption in UK transport in 1970 and 1987	36
2.7	Primary energy requirements of different travel modes in Britain	38
2.8	The influences acting upon transport energy demand	39
2.9	Travel by residents of different settlement sizes, 1972	40
2.10	Energy consumption in the VTE subsector by fuel	43
2.11	Energy consumption in the production of a car	43
3.1	Energy losses in a typical car journey	54
3.2	'Official' and 'empirical' estimates of average car fuel economy	57
3.3	Contributions to overall drag coefficient in a typical car	63
3.4	The effect of speed on fuel economy (average speeds)	65
3.5	The effect of speed on fuel economy (constant speeds)	66
3.6	Use of energy in the operation of an urban bus	70
4.1	Sample spreadsheet (blank) from SPACE	87

4.2	Engine size distribution of cars in Scenario 1 (fractions of total stock)	101
4.3	Total emissions of CO ₂ from personal travel in Scenario 1	106
5.1	Average car fuel consumption in the UK, 1970-88	117
5.2	Average car fuel consumption in the USA, 1970-88	119
5.3	Schematic diagram of a typical fuel cell	131
5.4	Energy-saving urban forms	146
5.5	Facilities supported by different populations	148
5.6	Modal distribution of trips in Milton Keynes and Almere	149
5.7	Public transport accessibility map for part of south-west London	154
5.8	Breakdown of modal transfer resulting from the Milan scheme	157
6.1	Engine capacity distribution resulting from fuel economy measures	177
6.2	Car fuel economy improvements targetted in Scenario 2	180
6.3	The growth in car mileage associated with Scenario 2 fuel economy improvement	181
6.4	Total emissions of CO ₂ from personal travel in Scenario 2	182
7.1	Total emissions of CO ₂ from personal travel in Scenario 3	204
7.2	The effect on car traffic growth of Scenario 3 measures	206

One day we walked down to Trafalgar Square. The tide was in, and the water reached nearly to the top of the wall on the northern side, below the National Gallery. We leant on the balustrade, looking at the water washing around Landseer's lions, wondering what Nelson would think of the view his statue was getting now....

She took my arm, and we started to walk westward. Halfway to the corner of the Square we paused at the sound of a motor. It seemed, improbably, to come from the south side. We waited while it drew closer. Presently, out from the Admiralty Arch swept a speedboat. It turned in a sharp arc and sped away down Whitehall, leaving the ripples of its wake slopping through the windows of august Governmental offices.

John Wyndham, *The Kraken Wakes*.

INTRODUCTION

INTRODUCTION

In the late 1980s, global warming grew in significance from a little-known scientific theory to an issue of deep concern for politicians, industrialists and the public alike. The realisation that human activities could be shifting the world's climate into a new, warmer epoch by enhancing the atmosphere's natural 'greenhouse effect' has implications for the entire world community.

In 1987, the discovery of the Antarctic ozone hole by British scientists prompted a global response on an unprecedented scale. The Montreal Protocol, signed in 1987 and revised in 1990, represents a commitment by governments worldwide to cooperate in the elimination of ozone-destroying gases. Recent measurements of stratospheric ozone levels have vindicated the sense of urgency in which this agreement was signed.

Many have pointed to the Montreal Protocol as an example of the kind of treaty that will be required in order to avert a 'greenhouse' catastrophe. At the time of writing, most governments have acknowledged the likelihood of climatic change through emissions of greenhouse gases, but have made no more than a minor response. The purpose of this study is to propose ways in which the UK government can contribute to an international programme for averting the threat of global warming.

This research project investigates the use of energy for personal travel, and the resulting emissions of greenhouse gases. Passenger transport, in Britain as well as in other western nations, is the fastest-growing source of greenhouse gases. As such, it warrants a degree of attention that has not hitherto been apparent. The aim of the research is twofold: firstly, it estimates the likely effect on greenhouse emissions of an ongoing, 'business as usual' trend for passenger transport in Britain; and secondly, it explores policy measures that might be deployed in order to control these emissions.

This thesis documents the results of three years' research, funded by the Science and Engineering Research Council. The core activity was the development of a computer model called SPACE which allows transport policy scenarios to be tested for their impact in terms of greenhouse emissions. The eight chapters are interspersed with three scenarios, representing alternative futures for personal travel in Britain. Data sets from the SPACE model can be made available to interested individuals.

Politicians in Britain and abroad are faced with many critical issues, including international stability, Third World debt, environmental protection and domestic economics. In all of these matters the objectives are easy to identify, but the means of achieving them invariably

less so. This study aims to steer a course through these technical and political intricacies and to indicate the steps that should be taken in order to lessen the conflict between the need to travel and the necessity for a stable atmosphere.

Geographical coverage of the study

This report covers personal travel within Great Britain. Northern Ireland is excluded because travel data are not published for the province in either the National Travel Survey or the Department of Transport's annual transport statistics. However, the results produced for Great Britain are likely to be relevant to the United Kingdom as a whole.

Terms and units of measurement

Quantities are generally expressed in terms of SI units. Although *miles* and *gallons* are in widespread use in Britain, the units *kilometres* and *litres* are used in this report. This prevents any confusion that may arise between imperial and US gallons. The following are conversion factors for some of the quantities commonly used in this study.

1 kilometre = 0.6215 miles

1 litre = 0.220 imperial gallon = 0.264 US gallon

1 megajoule (MJ) = 1,000,000 joules (J) = 0.278 kilowatt hour (kWh)

1 petajoule (PJ) = 1,000 terajoules (TJ)
= 1,000,000 gigajoules (GJ)
= 1,000,000,000 megajoules (MJ)

Acknowledgements

I should like to express my gratitude to Dr Stephen Potter for his invaluable guidance throughout the course of this research. I am indebted also to the many individuals who provided information and guidance on aspects of the project, both in Britain and in Berkeley, California. They include Steven Cousins, Godfrey Boyle, Lee Schipper, Dan Sperling, David Howard, Keith Buchan, Malcolm Fergusson, Phil Goodwin, Philip Steadman, David Lowry, John Whitelegg, Marc Ross, Jon Koomey, Peter Duerr, Alessandro Liberati, Damien Dallemagne and the late John Roberts.

I am grateful to SERC for funding the research and associated travel, and to the Open University's Faculty of Technology for the use of its facilities.

Chapter One

GLOBAL WARMING AND CLIMATIC CHANGE

1 GLOBAL WARMING AND CLIMATIC CHANGE

“Naturally occurring greenhouse gases keep the Earth warm enough to be habitable. By increasing their concentrations, and by adding new greenhouse gases like chlorofluorocarbons, humankind is capable of raising the global temperature.”

- Intergovernmental Panel on Climate Change, 1990

1.1. The issue of global warming

In the late 1980s global warming grew in prominence from a little-known climatic theory to a major concern on the public and political agenda. The principle that anthropogenic emissions could be altering the behaviour of the Earth's climate system gained recognition following a series of climatic anomalies worldwide. The threat of global warming is beginning to establish itself as a central component of policies on energy and land-use. The hazards of altering the composition of the atmosphere are no longer seen as a secondary issue, over which the greater concerns of energy production and economic growth take precedence.

1.2. The greenhouse theory

The 'greenhouse effect' is the popular term for the principle upon which global warming is based. The Earth's surface is heated by radiation from the Sun, most of which is radiated back into space at infrared (IR) wavelengths. However, trace gases in the lower atmosphere reabsorb a small amount of this outgoing radiation, warming the atmosphere and the surface of the Earth. Without this natural greenhouse effect, the temperature at the Earth's surface would be on average -19°C , compared with today's average of 15°C .

The analogy of a greenhouse is not strictly correct: the warming effect of a greenhouse is produced by a thin layer of glass that retains the warm air inside. In reality, greenhouse gases are present not as a thin layer but as trace gases throughout the atmosphere, and they warm the atmosphere by absorbing radiation rather than by restricting convection.

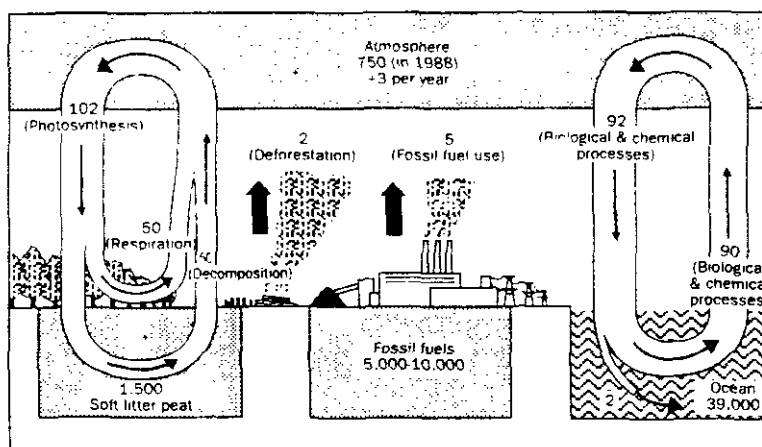
Under equilibrium conditions, the amount of solar energy entering the atmosphere is exactly balanced by the energy radiated back into space. The average temperature of the atmosphere

settles at a level in which this balance is established. Any additional factor that disrupts the balance by increasing the absorptive properties of the atmosphere is known as a *radiative forcing agent*. The atmosphere will tend towards conditions in which incoming and outgoing radiation are in equilibrium. If radiative forcing is increased as a result of rising levels of greenhouse gases, this implies an increase in atmospheric temperature.

1.3. Greenhouse gases

The most abundant of the 'greenhouse gases' is *water vapour*. In second place is *carbon dioxide* (CO_2), which is circulated in the biosphere as part of the natural 'carbon cycle', summarised in Figure 1.1. Human activities have created an imbalance in the carbon cycle and increased the amount of CO_2 in the atmosphere. This has taken place in two ways. Firstly, some of the 'sinks' for CO_2 have been removed. Forests form part of the CO_2 recycling process, and large quantities of carbon are 'stored' in the plants that they contain. By destroying these plants, and particularly trees, humans have released carbon to the atmosphere in the form of CO_2 . Secondly, the large-scale consumption of fossil fuels since the Industrial Revolution has released similarly large amounts of carbon dioxide to the atmosphere. Fossil fuels, in the form of the hydrocarbons coal, oil and gas, are used for a wide variety of purposes.

Figure 1.1 The carbon cycle



Source: Schneider, 1989 (in Leggett, 1990)

During the last 200 years, other greenhouse gases have begun to increase in concentration. In the hundred years preceding 1980, CO₂ accounted for 66 per cent of radiative forcing. In the 1980s the contribution of CO₂ emissions to global warming had fallen to 49 per cent of total radiative forcing, with the other 51 per cent due to other anthropogenic gases (Lashof and Tirpak, 1989). These are as follows:

Nitrous oxide (N₂O) is some 250 times more powerful as a radiative forcing agent than CO₂ per molecule, and results primarily from the combustion of fossil fuels and biomass, as well as the use of fertilizers;

Methane (CH₄) is 25 times more powerful than CO₂ and is produced when organic matter decomposes anaerobically. Major sources include leakage from gas pipelines, emissions from rice paddies, and fermentation in the digestive systems of livestock;

Chlorofluorocarbons (CFCs) and *halons* are a relatively recent invention, valued for their inert properties. They are up to 20,000 times more powerful than CO₂ as greenhouse gases. These gases have been used as aerosol propellants, refrigerants and foaming gases since the 1930s. The discovery in the late 1980s that CFCs are rapidly depleting the stratospheric ozone layer prompted a considerable reduction in their use, as this chapter will later explain. The atmospheric concentration of these gases had previously been rising at a growth rate of five per cent per year.

Replacements for CFCs are being developed by the chemical industries, in the form of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). These are generally less damaging in terms of ozone depletion and radiative forcing, but are nevertheless significant greenhouse gases (Fisher et al, 1990);

Tropospheric ozone (O₃) is also known to have a radiative forcing effect. It is formed by the reaction between nitrogen oxides (NO_x) and unburnt hydrocarbons in the presence of sunlight, as well as in some electronic machinery. Ozone at ground level is also known for its adverse effects on human health. It should be noted that the depletion of ozone in the stratosphere is a separate phenomenon, although there is some transfer of ozone from the stratosphere down to the upper troposphere. The contribution of tropospheric ozone to global warming 'may be significant, but cannot be quantified at present' (Watson et al, 1990).

Table 1.1 lists the principal greenhouse gases together with their current levels, growth rates and contributions to global warming. For different countries, emissions of all these gases can be amalgamated by combining annual production with the relative forcing effect of each gas. Table 1.2 gives the overall emissions of the 20 nations which are the greatest contributors to greenhouse emissions, in terms of total carbon equivalent and carbon equivalent per head of population.

The premise underlying this study is the hypothesis supported by the majority of atmospheric scientists: increased concentrations of greenhouse gases are beginning to induce an enhanced greenhouse effect, and *global warming* is likely to be the result.

Table 1.1 Summary of key greenhouse gases produced by human activities

	Carbon dioxide	Methane	CFC-11	CFC-12	Nitrous oxide
Atmospheric concentration	ppmv	ppmv	pptv	pptv	ppbv
Pre-industrial (1750-1800)	280	0.8	0	0	288
Present-day (1990)	353	1.72	280	484	310
Current annual rate of change	0.5%	0.9%	4%	4%	0.25%
Contribution to radiative forcing in the 1980s	55%	15%	----- 17% -----		6%

Notes: ppmv = parts per million by volume; ppbv = parts per billion by volume; pptv = parts per trillion by volume. The remaining 7% of radiative forcing is attributable to other CFCs. The contribution from ozone may also be significant, but cannot yet be quantified.

Source: Houghton et al, 1990.

Table 1.2 The 20 largest contributors to greenhouse forcing in 1988

Country	Total net additions (mtce)	% share of atmospheric green- house gas increase	Net additions per capita (tce)
United States	1,300	17.1	5.4
Australia	82	1.1	5.0
Canada	130	1.6	4.8
Myanmar ¹	160	2.1	4.0
USSR	1,000	13.5	3.6
Western Germany	210	2.7	3.4
United Kingdom	180	2.4	3.2
Brazil	430	5.7	3.0
Poland	110	1.4	2.9
Colombia	86	1.1	2.9
Italy	140	1.8	2.4
Japan	280	3.6	2.3
France	130	1.7	2.3
Spain	83	1.1	2.1
Thailand	95	1.2	1.7
Mexico	120	1.6	1.5
Indonesia	220	2.9	1.3
Nigeria	90	1.2	0.8
China	620	8.1	0.6
India	350	4.6	0.4
World	7,700	100.0	1.5

Notes: mtce = million tonnes of carbon equivalent; tce = tonnes of carbon equivalent.

Source: Hammond et al, 1991.

¹ Myanmar = Burma

1.4. Historical trends in greenhouse gas concentrations

Historical concentrations of CO₂ can be deduced through the analysis of *ice cores*: by drilling into ancient glaciers and analysing the air bubbles contained within them, an extensive history of global CO₂ levels can be obtained. The longest ice core drilled to date is over 3,000 metres long, and the information contained within it goes back over 200,000 years (Radford, 1992). Present-day concentrations of CO₂ can be measured using optical absorption techniques. On a timescale of millions of years, radiative forcing, primarily by CO₂, is believed to have decreased.

Superimposed upon this trend have been fluctuations in the atmospheric CO₂ concentration, on timescales of thousands of years, associated with major climatic events such as ice ages and meteoritic impacts. It is believed that changes in the Earth's orbit around the Sun, connected to various feedback mechanisms, are responsible for these periodic transitions between glacial and interglacial conditions (Gribbin, 1989).

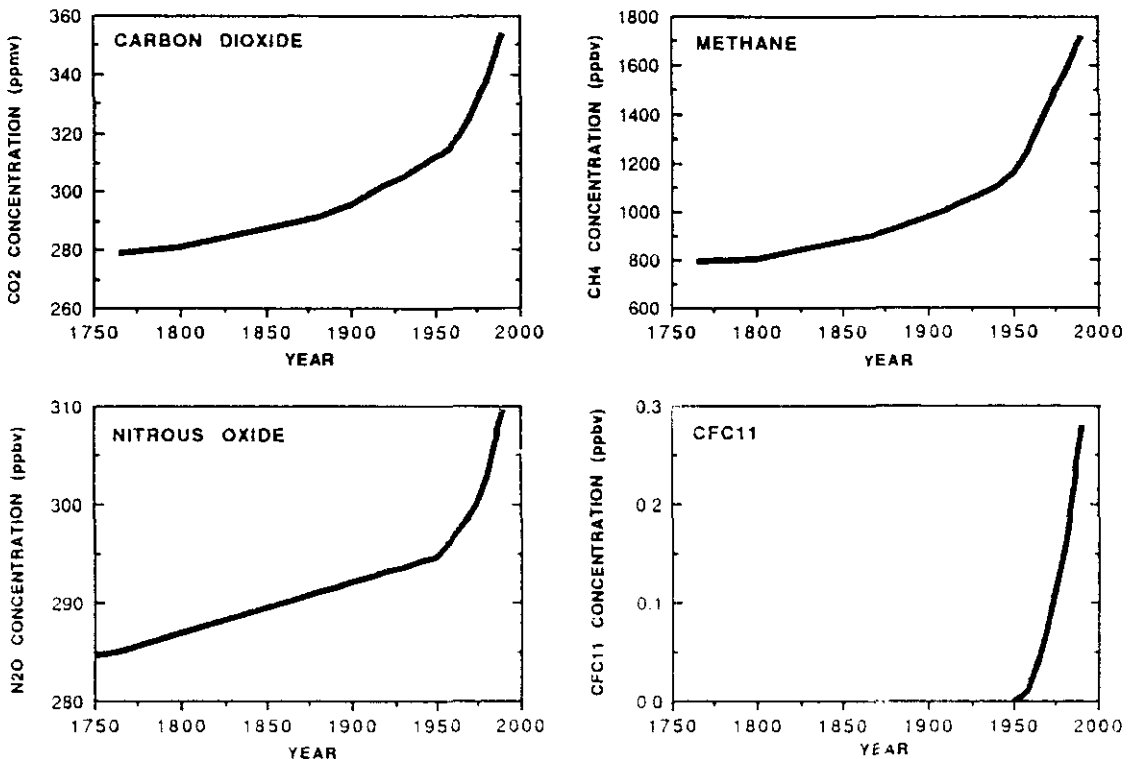
The most recent glaciation, associated with a CO₂ concentration of around 210 parts per million (ppm), began around 100,000 years ago and ended around 10,000 years ago. After this the atmospheric CO₂ level rose to a steady 280 ppm, the concentration found in air samples that have been trapped in polar ice for several thousand years. CO₂ remained at 280 ppm until around 1860, when the onset of industrialisation began to increase the atmospheric concentration. Since then, the widespread combustion of fossil fuels and the removal of forests has caused the concentration to rise by approximately 0.5 per cent per annum to its present level of around 350 ppm, as Figure 1.2 indicates.

Similarly, historical *temperatures* can be deduced from geological tests. Isotopic analysis of ancient ice formations, as well as sediments from oceans and lakes, reveals local temperatures at various stages of history (Figure 1.3).

1.5. Climatic change

In order to predict the likely effects of a warmer atmosphere, *general circulation models* (GCMs), running on powerful computers, are employed. GCMs are adaptations of models used in weather forecasting, which divide the Earth's surface into grid squares typically 300km across and solve the climatic equations at regular time intervals. To date there has been a broad consensus of opinion amongst modellers on the nature of global warming. It is predicted that an effective doubling in CO₂ concentration will raise the average global temperature by between 1.5 and 4.5°C. ('Effective doubling' refers to an increase in the concentration of *all* greenhouse gases equivalent in effect to a doubling of CO₂ alone.) At present rates of emission, effective doubling will take place around 2030 (Leggett, 1990).

Figure 1.2 Atmospheric concentration of greenhouse gases since 1750

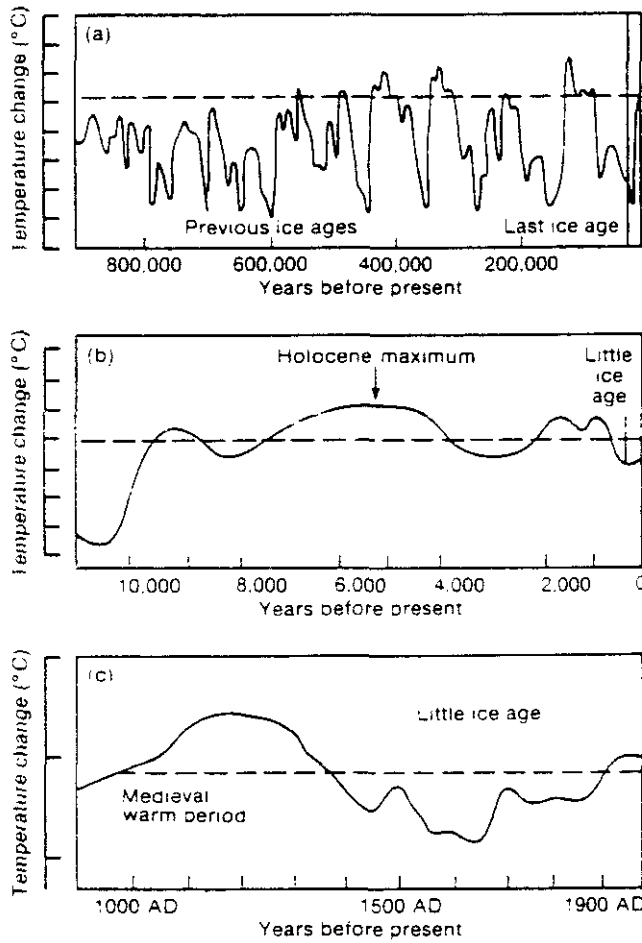


Source: Houghton et al, 1990.

Recent measurements of global temperature have demonstrated a clear warming trend. Many of the years in the 1980s have been amongst the hottest ever recorded. But these observations, despite their serious implications, are not necessarily indicative of a long-term warming. The shortcomings of measurements made in recent years are twofold. Firstly, they do not constitute a long enough warming trend for the causal link to be made with a long-term warming effect; and secondly, the global temperature record contains a significant element of 'noise', or short-period variability, from which sustained trends are hard to extract.

In addition, there are a number of other possible explanations for the observed warming. One theory is the low occurrence of volcanic activity in recent years and subsequent reduction in the cooling effect that atmospheric dust has upon the atmosphere. Another involves the possible effect of variations in solar activity. Finally, the warming may simply be a continuation of the increasing temperature associated with the end of the European 'mini ice age' that occurred some 300 years ago, and which is apparent in Figure 1.3.

Figure 1.3 Global average temperature since 900 AD



Source: Houghton et al, 1990.

The rate of warming projected by the Intergovernmental Panel on Climate Change (IPCC) is unprecedented in world history. Following the last glaciation, the temperature rose at an average rate of around 1°C per 500 years. By contrast, the IPCC 'best guess' prediction represents a warming rate of 1°C per 30 years.

1.6. Effects of global warming

The relatively rapid warming of the Earth's atmosphere would have a variety of impacts, which are expected to include the following.

1.6.1. Sea level rise

Amongst the likely consequences of a warmer climate is the probability that the global *sea level* will rise. Most of such a rise would be due to thermal expansion of the oceans, though some would result from the melting of land-based glaciers. The IPCC estimates that sea levels will rise by between 10 and 30 cm by the year 2030, with a 'best guess' of 20 cm. In 2100 it is predicted that sea levels will have risen by 30 to 100 cm, with a best guess of 65 cm. Given that a third of the world's population inhabits coastal regions, the consequences of losing these areas to the sea are very serious.

1.6.2. Rainfall and agricultural output

Concern has also been expressed in connection with global food production. Much of the agriculture upon which the world's population depends takes place in 'marginal' conditions; that is to say that a small change in climate in these areas could seriously disrupt their agricultural production. Recent droughts in the corn belts of the USA and the former USSR, as well as in less developed regions such as north-east Africa, have illustrated this fragility - and also led to speculation as to whether droughts will become more commonplace as the greenhouse effect takes hold. Regions identified by the IPCC Working Group 2 as being at risk include Northern and Southern Africa, India, the South-West USA, Central America and the Mediterranean.

In other areas, it is predicted that global warming will lead to increased rainfall, with possibly detrimental effects. This is particularly the case at higher latitudes.

1.6.3. Adverse climatic events

It appears likely that additional radiative forcing will be associated with an increase in the number and severity of climatic adversities. There are indications that the number of droughts, floods, storms and so on, when measured as a total over each of the last three decades, has risen substantially (Timberlake, 1988). The year 1988, for example, was the year of the great droughts in the corn belts of the USA and the former USSR, and the catastrophic hurricanes Joan and Gilbert which severely disrupted the ecology of Nicaragua and the Caribbean. Speculation regarding the effects of global warming upon the polar icecaps was heightened in 1987 by the dislocation of an iceberg 90 miles long from Antarctica, which drifted northwards and broke up. In September 1989, ice in a region to the north of Greenland was reported to have thinned from 6.7 to 4.5 metres between 1976 and 1987. Similar effects were observed in the Antarctic, where average air temperatures rose by 1.1°C between 1982 and 1986 (Highfield, 1989).

Other unusual weather phenomena, such as the cyclone that devastated Bangladesh in April 1991, have been observed but, by their complex and unpredictable nature, provide little contribution to the evidence for global warming. Although one of the main predictions made by climate modellers is an increase in the severity and frequency of climatic adversities, they cannot say for sure whether a drought or flood is the direct result of global warming or simply a 'natural' event. Nor is it possible to predict with any confidence where and when the next climatic anomaly will take place.

Equally important is how the weather patterns of individual continents will be affected. There is the possibility of a 'Mediterranean' climate being established in southern England. However, there is also speculation that the temperate Gulfstream which warms the British Isles during the winter could be affected, leading to more severe winter weather.

1.6.4. Biological diversity

Natural habitats are threatened not only by the prospect of altered climatic conditions. For many species, the rapid *rate* of change poses the greatest threat. Dobson et al (1989) have indicated that the effect of a one-degree rise in temperature is equivalent to a change in latitude of up to 100 miles. The IPCC 'best guess' prediction implies that such a change could take place in a period of just 30 years. Many species of flora and fauna would have to migrate towards the poles in order to find favourable conditions, and concern has been expressed that the required rate of migration is too high for some plant varieties. Many habitats may be lost altogether; and some species, such as the migrating fish of the Atlantic, may be threatened if the natural signals which prompt their reproductive activity are disrupted.

1.6.5. Human health

Haines (1990) has catalogued the likely effect of climate change on human health. The effects of climate change upon food production clearly have serious implications for nutrition. Furthermore the spread of communicable diseases, particularly in the Third World, is likely to increase as a result of elevated temperatures. In the developed world the hazards range from temperature-related disorders to a deterioration in mental health resulting from environmental catastrophes.

1.6.6. Political stability

The implications of climatic change are very grave for low-lying settlements such as Bangladesh, Egypt and the Netherlands. Many coastal cities will incur severe difficulties should a change in sea level take place. Similarly a change in precipitation is likely to endanger millions of lives. Large numbers of 'environmental refugees', combined with a steadily rising global population, are likely to have a destabilising effect on global politics.

1.6.7. Feedback mechanisms

Finally, it should be noted that global warming may be amplified by a number of possible *feedback mechanisms* which may increase the effects of greenhouse emissions. Perhaps the greatest uncertainty in the global warming debate concerns the way in which the Earth's natural systems will react to a CO₂-rich atmosphere. Of particular concern are the oceans and the microscopic life-forms that live in them: their photosynthetic activity may increase, absorbing more CO₂ from the atmosphere, or alternatively they may be adversely affected and thereby contribute further to the rising temperature.

The possibility of increased cloud cover in a warmer world may lead to a moderation of surface warming because of a reduction in the amount of sunlight reaching the Earth's surface. Alternatively, melting icecaps may release large amounts of methane from the thawing subsoil in polar regions, contributing further to radiative forcing. The loss of ice might also lead to increased absorption of solar radiation due to reduced surface albedo.

Only some of these feedbacks are included in GCMs; for others, it has not yet been established whether the effect is positive or negative in nature. For a fuller discussion of these phenomena see Schimel (1990) and Woodwell (1990).

1.7. Future greenhouse emissions

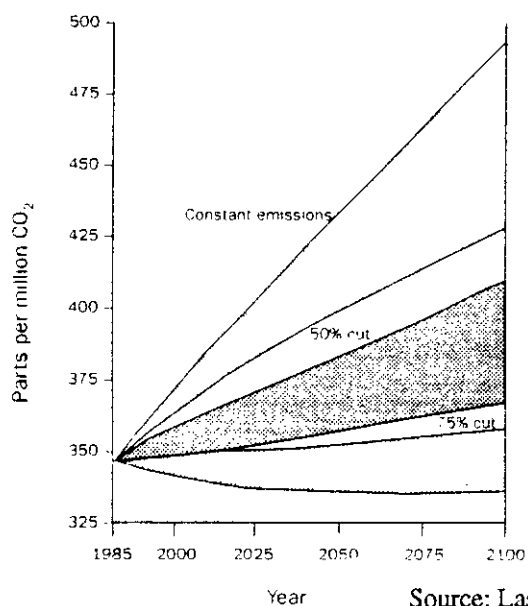
1.7.1. Carbon dioxide

If emissions of CO₂ continue at present rates, the concentration of this gas in the atmosphere may be expected to reach almost 500 ppm by 2100. Of crucial importance is the observation that stabilising emissions is *not* equivalent to stabilising atmospheric concentration. In order to halt the growth of CO₂ in the atmosphere, significant cuts in emissions are required.

Figure 1.4 illustrates the magnitude of reductions that must be achieved if CO₂ concentrations are to be limited. A cut of over 75 per cent is needed to hold atmospheric concentrations at their 1985 level of just below 350 ppm. This view is similar to that of

Kelly (1990), who estimates that a 70 per cent reduction in CO₂ emissions by 2020, among other measures, will be needed in order to achieve a 'stabilizing scenario'.

Figure 1.4 Impact on atmospheric CO₂ concentrations of various reduction strategies



Source: Lashof and Tirpak, 1989.

1.7.1. International targets

In June 1988 an international conference *The Changing Climate* was convened in Toronto to negotiate a global response to the issue of climatic change. The conference recommended that industrialised countries reduce their CO₂ emissions by 20 per cent by the year 2005, and 50 per cent by 2025.

Responses so far to the threat of global warming may be categorised into three types:

- 'No response': in the light of scientific uncertainty over the consequences of global warming, no national targets for emission controls are established;
- 'Stabilise emissions': a target is set for holding emissions down to present-day levels, typically by 2000 or 2005;
- 'Reduce emissions': in order to approach the goal of stabilising the *atmospheric concentration* of greenhouse gases, reduction strategies are established. Typically cuts of around 20 per cent by 2005 are envisaged, in

accordance with the Toronto recommendations. Greater reductions in emissions may be expected in the period following 2005.

Table 1.3 compares the responses of different nations, in terms of targets for reducing CO₂ emissions. The EC is committed to a policy of stabilising emissions at 1990 levels by the year 2000. However, the situation within the EC is varied: for example, Germany has opted for a 25 per cent cut by 2005, but the UK plans only to achieve stabilisation by 2000.

Table 1.3 National responses to global warming

Country	Target details	% contribution at present
No controls:		
USA	Not in favour of emission controls	22.0
Ex USSR	Not in favour of emissions controls	18.4
Stabilisers:		
Japan	Stabilise at 1990 levels by 2000	4.4
UK	Stabilise at 1990 levels by 2000	2.8
Canada	Stabilise at 1990 levels by 2000 'as a first step'	2.0
Italy	Stabilise at 1990 levels by 2000. Parliamentary resolution for 20% cut by 2005	1.8
Belgium	Stabilise at 1988 levels by 2000	0.5
Austria	Support stabilisation at 1990 levels by 2000. 20% cuts proposed by environment minister	0.3
Finland	Stabilise at 1990 levels by 2000, at least	0.3
Sweden	Stabilise at 1988 levels by 2000	0.2
Norway	Stabilise at 1990 levels by 2000	0.2
Switzerland	Has supported stabilisation at 1990 levels by 2000	0.2
Ireland	Support stabilisation at current levels by 2000	0.1
Reducers:		
Germany	25% reduction on current levels by 2005. Agreed by cabinet but not yet ratified by parliament.	3.2
Australia	20% reduction by 2005	1.1
Netherlands	Stabilise by 1995, 3-5% reduction by 2000	0.7
Denmark	20% reduction by 2000, up to 50% by 2030	0.3
New Zealand	20% reduction by 2000	0.1

Source: Fagan, 1990.

The USA and former USSR have not agreed to set a national target for CO₂ emissions, but are nevertheless giving attention to areas in which reductions might be achieved. In many cases the USA strategy has favoured 'no regrets' policies, or measures that are known to have no adverse effects upon society. If a 'no regrets' measure is later deemed to have been unnecessary (perhaps if global warming fails to materialise on the scale presently anticipated) there will be no overall loss to society.

1.7.2. The IPCC recommendations

Table 1.4 summarises the recommendations of the IPCC with regard to reductions in emissions of all the greenhouse gases. This study will investigate the ways in which the UK transport sector can contribute to the different policy responses described in 1.7.1 above.

Table 1.4 Cuts in emissions needed for a stabilisation of greenhouse gases at present atmospheric levels.

<u>Greenhouse gas</u>	<u>IPCC estimated cut (%)</u>
CO ₂	at least 60
CH ₄	15 - 20
N ₂ O	70 - 80
CFC-11	70 - 75
CFC-12	75 - 85
HCFC-22	40 - 50

Source: Houghton et al, 1990

1.7.3. The Montreal Protocol

In 1987, public alarm was raised following the discovery of a large 'hole' in the stratospheric ozone layer above Antarctica. Concern focused primarily on the health hazards of ultraviolet radiation, from which the ozone layer shields the Earth. Ultraviolet is associated with a variety of diseases including skin cancers and cataracts. Ozone depletion was attributed to emissions of CFCs, but the implications of CFC emissions for global warming were generally regarded as an issue of secondary importance.

The discovery of the 'ozone hole' prompted the first ever international treaty for environmental protection, the Montreal Protocol. The outcome of the negotiations, completed on 16 September 1987, was a broad agreement to reduce production and emission of five CFCs and three halons. The terms of the Protocol were as follows:

- ❑ Consumption of the CFCs to be frozen at 1986 levels in 1989, and cut by 20 per cent by 1994, and 50 per cent by 2000;
- ❑ Production of the CFCs to be no more than 10 per cent greater in 1989 than in 1986, and to be reduced by 10 per cent and 35 per cent by 1994 and 2000 respectively;
- ❑ Consumption of halons to be frozen at 1986 levels in 1992.

(Warr, 1991)

In June 1990 the terms of the Montreal Protocol were revised at an international conference held in London (Milne, 1990). An international agreement was secured for a complete elimination of CFCs by the year 2000, with intermediate cuts of 50 and 85 per cent in 1995 and 1997 respectively. Halons were also to be phased out, with some exceptions, by 2000, with a cut of 50 per cent by 1995. India and China agreed to sign the Protocol in 1992.

Renewed urgency was given to the issue of ozone depletion in April 1991, when observations from NASA's satellite-borne Total Ozone Mapping Spectrometer revealed that northern mid-latitudes were losing ozone at a greater rate than was previously thought. These observations may result in yet more stringent targets for the elimination of CFCs and halons.

Whilst international difficulties are likely in the attempt to secure CO₂ reduction targets, it appears likely that a virtual elimination of CFCs and halons is possible in the near future, leading to an eventual reduction in the atmospheric concentration of these gases. As mentioned earlier, however, the gases that are used in place of CFCs also have a measurable radiative forcing effect, and from a global warming perspective should not be regarded as benign.

1.8. Summary

A consensus of scientific opinion, embodied by the IPCC, has agreed that global warming will be a likely consequence of the accumulation of various anthropogenic gases in the atmosphere. But there is uncertainty surrounding

- ❑ the scale of the warming effect and its influence upon global climate;
- ❑ the effect that warming will have upon the world's ecosystems; and
- ❑ the social and economic problems that global warming will create.

Accordingly, there is a wide variation between the responses of different countries. The most common strategy among industrialised nations is to stabilise CO₂ emissions at present levels, as a first step towards more stringent reductions. The IPCC, on the other hand, has indicated that a reduction of at least 60 per cent will be necessary in order to stabilise the atmospheric concentration of this gas. The international convention for phasing out CFCs will have a beneficial effect in terms of radiative forcing.

Although preliminary actions have been taken in order to curb the emission of greenhouse gases into the atmosphere, it is unlikely that these measures will be sufficient to avert a warming trend. If the global warming theory proves to be correct, it will be necessary to achieve greater reductions in emissions than those currently anticipated in order to halt climatic change.

Chapter Two

THE NATURE OF GREENHOUSE EMISSIONS FROM PERSONAL TRAVEL

2. THE NATURE OF GREENHOUSE EMISSIONS FROM PERSONAL TRAVEL

“In the United Kingdom, as in most other industrialised countries, combustion of fossil fuels for many purposes including transport is the major source of emissions which pollute the air.”

L. Watkins, Transport and Road Research Laboratory

2.1. Defining a transport system

In order to quantify the emission of greenhouse gases from transport, it is necessary first to define the transport system and its boundaries. Analyses of energy consumption and greenhouse emissions in transport are often based on the assumption that transport activities are defined exclusively by their operation. Accordingly, non-operational activities, such as the manufacture and maintenance of vehicles and infrastructure, are excluded.

The difficulties associated with quantifying all the sources of emissions are numerous, but it is nevertheless important to estimate the contribution of secondary activities to overall greenhouse emissions from personal travel.

2.1.1. Components of overall energy demand

Howard (1990) has estimated the relative energy demands of different aspects of transport, and his figures are presented in Table 2.1. If a ‘wide view’ is adopted, the *operation* of transport accounts for at least two thirds of total energy use.

2.1.2. Primary energy and delivered energy

The distinction between *primary* and *delivered* energy is crucially important in this respect. The primary energy consumption of a sector such as transport takes into account the energy demand of obtaining, processing and delivering the fuel. Delivered energy, on the other hand, refers only to the energy consumed at the point of use, and takes no account of the energy costs involved in providing the fuels.

Table 2.1 Total energy use from UK transport demand

Activity	Energy use (TJ)	% of total
Vehicle operation	1563.1	66 - 72
Vehicle manufacture	40.0 - 157.0	2 - 7
Raw material production	108.1	5
Vehicle maintenance	94.2	4
Infrastructure provision	32.7	1
Energy generation	344.2 - 423.2	14 - 19
Total	2182.3 - 2378.3	100

Source: Howard, 1990.

The energy used *in situ* by a vehicle can be considerably less than the overall energy consumption. This is particularly true in cases where the transport system is powered by electricity, because much of the primary energy is lost as a result of the inefficiencies of the generation and transmission processes. The average efficiency with which steam turbine-type power stations¹ produce electricity from their original fuel is between 30 and 35 per cent (Department of Energy, 1991). Further losses are incurred during transmission.

In the case of vehicles powered by internal combustion (IC) engines, primary energy demand includes the energy required to refine and deliver the petroleum-based fuels, which is additional to the 'delivered' energy content of these fuels. The major energy component of energy consumption is the conversion of chemical energy to tractive work within the vehicle. This process is more efficient in electric vehicles than in IC-engined vehicles, but, as noted above, a large proportion of energy is wasted during the production of the electricity itself (Department of Energy, 1981).

Although primary energy consumption includes most aspects involved in the provision of fuel, it does not take the comprehensive view of transport described above, in which all other processes associated with transport, such as infrastructure provision, raw materials extraction and vehicle manufacture, are taken into account.

¹ Excluding nuclear power stations

Although this study will take some consideration of energy consumption in these other activities, the main criterion adopted will be vehicle operation and the primary energy consumed therein.¹ This is because the measurement of primary energy provides a useful compromise between the complexities of describing all the processes involved (which would have exceeded the time and resources available for this study) and the limitations associated with the quantity 'delivered energy'.

An important consideration in using primary energy as the main measurement in this study is the fact that for transport activity it includes the bulk of all energy use. As Table 2.1 shows, the primary energy consumption associated with transport accounts for between 80 and 91 per cent of all transport-related energy demand.

2.1.3. Energy generation

The use of primary energy as a unit of measurement in this study means that the process of producing and distributing energy must be examined. In the case of transport, this embraces the various forms of energy used to power vehicles.

Almost all motorised travel makes use of *petroleum* as an energy source. However, the various forms of petroleum fuel have different energy demands associated with their production. Table 2.2 expresses these losses in fractional form, together with the loss associated with electricity production. Although the various petroleum-based fuels show some variation, the striking feature is the exceptionally high energy demand associated with electricity production. Typically two-thirds of primary energy is lost in the production of electricity, as a result of inefficiencies and, more significantly, thermodynamic limitations.

The large energy losses associated with electric traction are due primarily to these constraints. As noted above, the average thermal efficiency of such plant, defined as the energy output divided by the energy input, is less than 35 per cent.

Estimates have been made of the relative efficiencies of comparable electric and IC-engined vehicles (Department of Energy, 1981). The efficiency with which an electric vehicle (EV) converts mains electricity to propulsive work is 70 per cent, compared with 15 per cent for a conventional IC-engined vehicle. But when the fuel production processes are taken into account, the overall propulsion efficiency of the EV drops to 19 per cent, whilst that of the IC-engined vehicle is marginally reduced to 13 per cent.

¹ Occasionally, where only data for delivered energy are available, this measure has had to be used instead.

Table 2.2 Energy losses in the production of transport fuels

Fuel	% loss in production and distribution
Motor spirit	11
Diesel	3
Aviation fuel	4
Electricity for trains	68
Electricity for underground	73

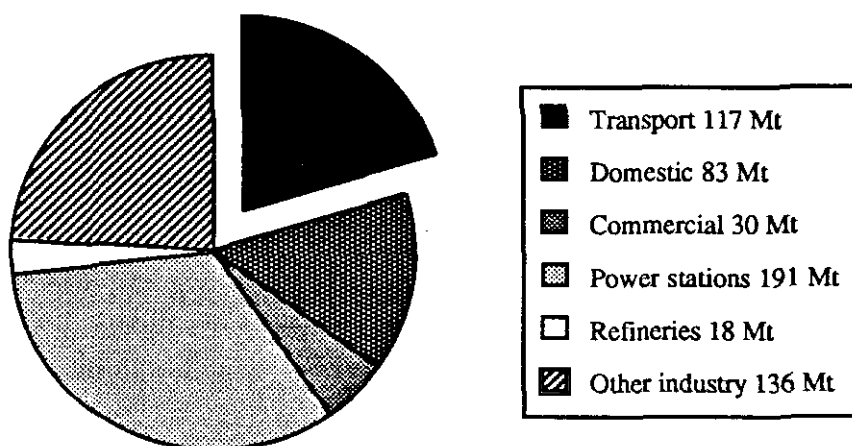
Source: Zeevenhooven, 1990.

In summary, over 80 per cent of the energy used in transport operations is associated with the operation of vehicles, together with the production and delivery of their fuel. Although electric traction is more efficient at the point of use than IC engines, there are substantial energy losses in the generation and distribution of electricity.

2.2. Transport's share of CO₂ emissions

In 1989, total ground-based emissions of CO₂ in the UK amounted to 576 million tonnes (Department of Transport, 1991a). The operation of passenger and freight transport was responsible for around 20 per cent of this quantity, as Figure 2.1 illustrates. The percentage is higher if subsidiary activities, such as vehicle manufacture and infrastructure provision, are included. Figure 2.2 shows how the 'transport' segment of Figure 2.1 is itself divided between different forms of transport, according to the author's calculations. The figure for CO₂ emissions from all transport in 1990 is estimated to be 121 million tonnes (Mt). Details of calculations are given in Appendix 1.

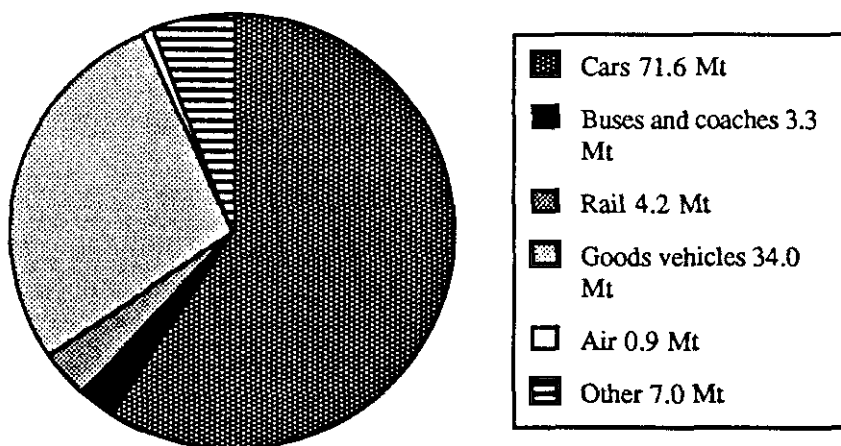
Figure 2.1 UK CO₂ emissions by end-use in 1989



Total: 576 Mt

Source: Department of Transport, 1991a.

Figure 2.2 CO₂ emissions by different transport modes, 1990



Total: 121 Mt

The chart refers to the operation of transport, and excludes peripheral activities such as those detailed in Table 2.1. Source: author's estimates. For details of calculations, see Appendix 1.

During the era of steam railways, coal was the principal transport fuel in Britain. During the twentieth century, oil, in the form of petroleum, has gradually replaced coal. ('Petroleum' is a general term for oil products, including motor spirit, diesel and aviation fuel.) Transport now derives its energy almost exclusively from oil. In 1989, over 99 per cent of transport's delivered energy was derived from petroleum (Department of Transport, 1991a).

2.2.2. Energy use by walking and cycling

Within the spectrum of transport modes, two forms of travel can be identified as being distinctly separate in nature from the rest. These are the *non-motorised* modes, walking and cycling. Being powered entirely by human effort, they are fuelled by the complex system of energy production within the human body.

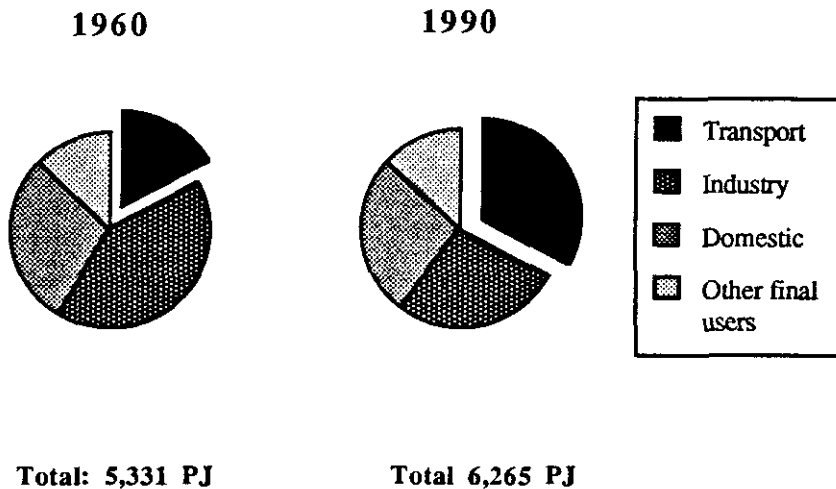
Although human respiration is a producer of at least two greenhouse gases, carbon dioxide and methane, the approach taken in this study is to assume that this source of emissions is negligible. In the first place, humans, together with other animals, are part of the natural carbon cycle (see Chapter One) in which carbon is circulated between living matter and the atmosphere. It would be almost impossible to evaluate how much *extra* methane and carbon dioxide are produced by these travel modes, in addition to the quantity produced by a sedentary human.

2.3. The growth of energy use in transport

Of crucial importance is the observation that transport's share of energy consumption, and CO₂ emissions, is *increasing*. In 1960, passenger and freight operations accounted for 17 per cent of delivered energy in the UK, whilst in 1990 their proportion had risen to 33 per cent (Department of Energy, 1991).¹ Figure 2.3 compares the 1960 and 1990 distributions of end-uses in the UK energy market.

¹ Figures for primary energy are not available. Transport's share of primary energy consumption is less than its share of delivered energy consumption, because of the relative efficiency with which crude oil is converted to petroleum products.

Figure 2.3 Energy consumption by final user in the UK, 1960 and 1990 (heat supplied basis)



Source: Department of Energy, 1991.

2.3.1. Factors influencing transport's use of energy

Energy consumed by transport may be separated into *freight* and *passenger* operations. This study is restricted to passenger transport, whose nature is in many ways different from that of freight operations.

Energy consumption, and carbon dioxide emissions, in the passenger sector are determined by three variables, namely:

- the *volume* of motorised travel;
- the *mode* of transport employed to undertake travel; and
- the *specific energy consumption* of the modes involved.

As we have seen, the net effect of these factors historically has been an increase in energy consumption. The three variables are examined in more detail below.

2.3.2. Modes of transport covered by this study

This study aims to cover all the significant modes of personal travel employed within Britain. It includes air travel, for journeys beginning and ending in Britain, but excludes waterborne modes such as ferry, hovercraft and hydrofoil. Figures for waterborne travel are

not readily available in the form of passenger kilometres, and the data tend to be dominated by overseas travel, which is beyond the scope of this study. Waterborne modes are of little overall significance for passenger travel in Britain.

In the following chapters 'private cars' refers to all privately-owned cars, including 'company cars' given to employees for business travel or as income-in-kind. It also includes taxis and private hire cars.

'Buses and coaches' include public service vehicles of all sizes and for all operations, and cover the whole range of services from urban bus operations to long-distance coach travel.

Table 2.3 shows how the bus and coach population of Great Britain is divided according to vehicle category. Diesel-engined vehicles dominate the sector, with petrol-engined vehicles comprising mainly minibuses of up to eight seats in capacity.

'Rail' includes British Rail together with a number of urban rail operators. British Rail divides its passenger operations into InterCity, Network South East (NSE) and Regional sectors. Together, these account for around 84 per cent of rail passenger kilometres. The remainder is accounted for by a growing number of rail systems in large towns and cities.

The London Underground is the largest urban rail system in Britain, with the Tyne and Wear Metro being the only other city-wide example. There is a small underground railway in Glasgow. More common in cities are surface suburban railways, such as the Strathclyde and Manchester networks, which are operated by British Rail.

Table 2.3 Bus and coach population, 1986

Vehicle type and seating capacity	Diesel-fuelled	Petrol-fuelled	Total
Minibuses up to 8 seats	29,773	26,837	56,610
Single and half-deck coaches	40,664	2,478	43,142
Double-deck and standee buses	27,795	425	28,220
Total	98,232	29,740	127,972

Source: Department of Energy, 1989.

A third type of urban railway is *light rail transit* (LRT). The London Docklands Light Railway was the first in Britain, and opened in 1987. This was followed by Manchester (1992) and Sheffield (planned for 1993). LRT is typically based on tram technology, and

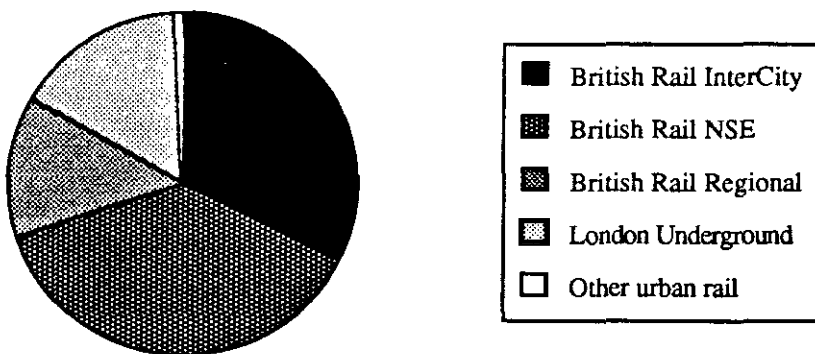
operates on a mixture of streets, converted rail lines and newly-built track. Although the Docklands Light Railway uses third-rail electric traction, overhead lines at 1,500 volts DC are now becoming the accepted standard for British LRT systems.

Electric traction for rail derives power either from overhead lines (25kV AC) or from a third rail (650-800V DC). Overhead lines transmit electricity with an efficiency of around 98 per cent; third rail systems have an efficiency of approximately 89 per cent. The substations, which receive electricity from the National Grid and supply it to the rail network, operate with efficiencies of between 95 and 99 per cent (Department of Energy, 1989).

Figure 2.4 shows how passenger kilometres are divided between the different rail operators in Britain. Among these categories, different types of rolling stock are operated, with distinct energy consumption characteristics.

Finally, 'air' refers to domestic aircraft operations only. This study is concerned with passenger transport in Britain, and by definition excludes overseas journeys. In 1986, domestic journeys (those beginning and ending in the UK) accounted for just four per cent of the 90 billion passenger kilometres travelled from UK airports. Domestic flights therefore represent a small fraction of total air travel (Department of Energy, 1989).

Figure 2.4 Rail passenger traffic in Britain, 1990



Total: 39.8 billion passenger km

Source: Department of Transport, 1991a.

2.3.3. The growing demand for personal travel

Since the Second World War there has been a sustained growth in personal travel. Between 1952 and 1990 the total distance covered grew from 197 to 660 billion passenger kilometres, more than a threefold increase (Department of Transport, 1991a).

Travel *volume* is a measure of the amount of travel undertaken, measured in *passenger kilometres*. Table 2.4 shows that the historical growth in travel volume has involved an increase in both the *number* and the *length* of journeys undertaken. However, there is evidence that the number of journeys per person per week is stabilising, with more of the growth in passenger mileage being attributable to a lengthening of trips. Potter and Hughes (1990) show that in the decade from 1975 to 1985 the average number of journeys undertaken per person increased only marginally, from 18.2 to 18.5 per week, while the weekly travel distance increased by a third.

Table 2.4 Journeys and travel distance per person, 1965 and 1985.

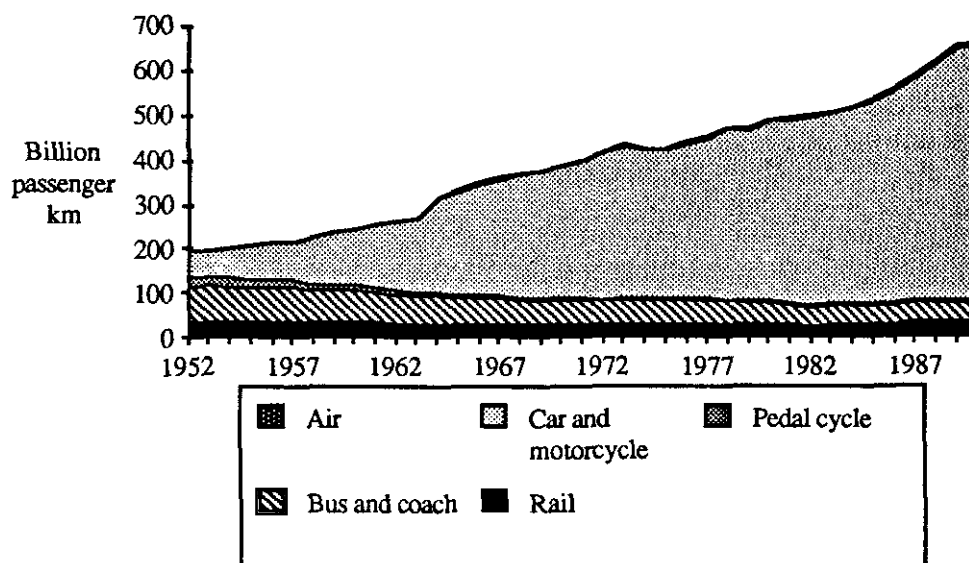
	1965	1985
Journeys per person per week	11.2	13.2
Average journey length (km)	10.1	12.1
Travel distance per person per week (km)	112.6	160.9

Note: the figures exclude journeys shorter than one mile. Source: Department of Transport, 1988.

2.3.4. Trends in modal distribution

The historical increase in personal travel volume has not been divided equally between different modes of transport. Figure 2.5 shows that the dominant effect has been a large growth in car travel. There has also been a strong increase in air travel, but from a very small base.

Figure 2.5 Passenger transport by mode, 1952 to 1990



The graph excludes 'walk' trips. The 1985 National Travel Survey shows that a person walks on average 8 km per week: this leads to a total annual national figure of around 2.3 billion kilometres.

Source: Department of Transport, 1991a.

The increase in car travel can be related to rising car *ownership* in Britain. Between 1970 and 1989, the number of cars in Britain increased from 214 to 368 per thousand population (cpt) (Department of Transport, 1991a). The volume of travel by rail has changed very little since 1952, whilst the use of buses, coaches and pedal cycles has declined.

2.3.5. Trends in energy consumption

The relative energy consumption of different travel modes has an important influence on overall energy use. The energy consumption of a travel mode is measured by the amount of energy required to carry one person a certain distance, termed *specific energy consumption* (SEC) and measured in megajoules per passenger kilometre (MJ/pkm). This quantity is a function of two factors: *vehicle fuel economy*, measured in megajoules per vehicle kilometre (MJ/vkm), and the number of persons carried by the vehicle, the *occupancy*.

The average occupancy of vehicles can be notoriously difficult to evaluate, given the enormous range of loads experienced by some modes. In particular, buses and trains may be operated almost empty at some times, whilst on other occasions the load factor may be well

over 100 per cent as a result of additional standing passengers. ('Load factor' is a term describing the fraction of places occupied.)

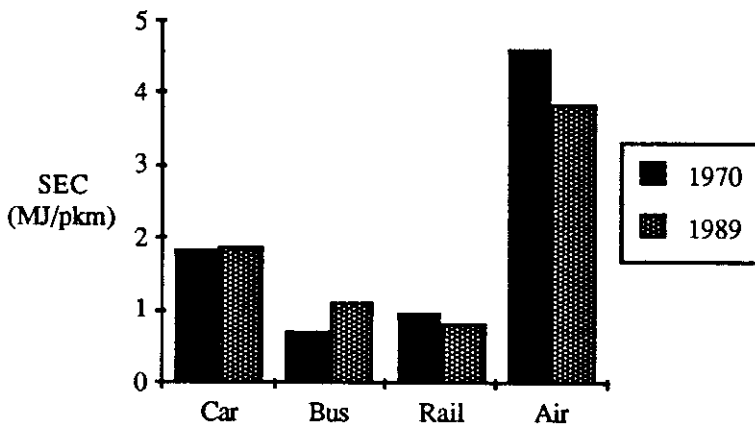
In the period 1970 to 1990, the average number of passengers carried by a car declined from 1.86 to 1.70, whilst on buses the equivalent figures were 14.8 and 8.7. On railways, average occupancy was unchanged at 98 persons per train (Department of Transport, 1991a). The decline in load factors for cars and buses thus partially explains the increase in energy consumption between 1970 and 1987 that can be seen in Figure 2.6.

The SEC of car travel has increased marginally since 1970, chiefly as a result of declining occupancy. Improvements in vehicle fuel economy have not been sufficient to counteract this effect.

Buses show a greater increase in SEC over the period 1970 to 1989, which is attributable to two factors. Firstly, in recent years there has been a trend towards smaller vehicles. Although these typically have better fuel economy, they carry proportionately fewer passengers than a large vehicle. Secondly, the patronage of buses has declined, leading to lower average load factors.

Rail travel has shown an improvement in SEC, as a result of technological improvements in the rail stock and the use of smaller trains on more lightly-loaded routes.

Figure 2.6 Energy consumption in UK transport in 1970 and 1987



Source: Schipper et al, 1990.

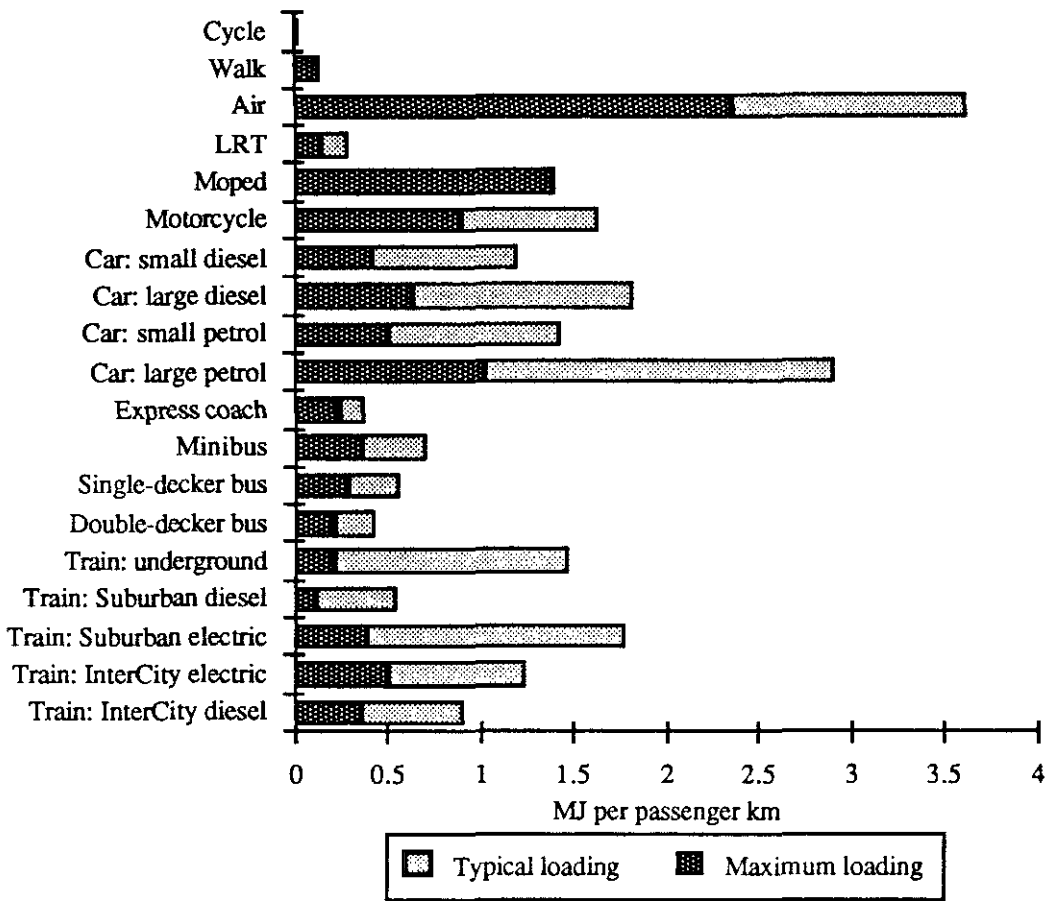
The SEC of air travel has shown a significant improvement, dropping by 75 per cent between 1963 and 1986. Since 1986 this improvement has levelled off (Department of Energy, 1989). The reduction in SEC is attributable not only to advances in aircraft technology, which are discussed in more detail in Chapter Three, but also to an increase in occupancy, which has been the result of larger aircraft and increased load factors. A growth in non-scheduled operations has contributed to the latter. A detailed discussion of trends in aircraft fuel consumption appears in Chapter Three.

There is a wide variation in energy consumption between different travel modes. Figure 2.7 illustrates the primary energy consumption of various travel modes in operation in Britain, under both 'typical' and '100 per cent' loading conditions. Aircraft and large cars rate as the most energy-intensive modes. For rail, diesel trains generally use less energy per passenger kilometre than electric, as a result of large inefficiencies in the generation of electricity. Double-decker buses and LRT systems are among the most energy-efficient of motorised travel modes, and for all modes the effect of loading factor, indicated by the ratio of the dark area to the whole area, is very significant.

2.3.6. Summary: factors influencing transport's use of energy

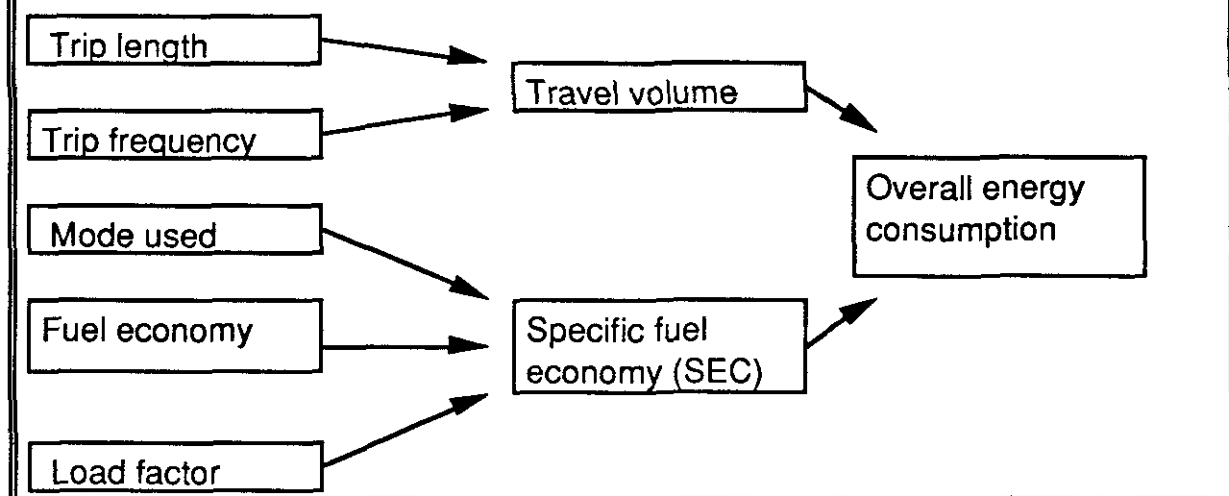
The aspects of energy demand described above are summarised in Figure 2.8. It should be noted that this representation is a simplification of the true picture. In reality there are other influences and feedbacks between the factors itemised in the diagram. In particular, it is widely known that the choice of travel mode has an influence on both the frequency and length of journeys, and therefore affects more than just the fuel economy. Nevertheless, Figure 2.8 is a useful representation of the major influences on the energy demand of personal travel.

Figure 2.7 Primary energy requirements of different travel modes in Britain



For details of sources and calculations see Appendix 2.

Figure 2.8 The influences acting upon transport energy demand



2.3.7. The influence of human settlement patterns on energy use

The historical increase in personal travel is a function of several trends. Since the Second World War, car ownership has increased substantially. Alongside this trend, the real price of motor fuel has fallen: the price of petrol dropped by around 15 per cent between 1970 and 1988. Although these factors are important influences in themselves, they have also contributed to longer journeys via other, indirect means. In particular, a long-term trend towards dispersed settlement patterns has been a side-effect of these changes in travel behaviour.

The pattern of land-use has a direct influence on all of the areas represented in Figure 2.8. The spatial separation of activities such as homes, shops, workplaces and leisure pursuits determines journey lengths, and hence travel volume. Settlement patterns also influence the *modes* of transport that are used, leading to a positive feedback loop - although modal choice is also heavily dependent on 'nonspatial' policies. Land-use patterns can also indirectly affect load factors and specific fuel economy for particular modes.

Since the 1960s the population of Great Britain has been moving away from urban areas and into lower-density settlements (Champion, 1987). In 1985, 51 per cent of Britons lived in settlements of population 100,000 or more; 38 per cent lived in settlements of between 3,000 and 100,000 people; and the remaining 11 per cent lived in 'rural' settlements, of fewer than 3,000 people. A relationship between urban size and transport demand has been demonstrated by Maltby et al (1978), and is illustrated in Figure 2.9. Similarly, Potter and

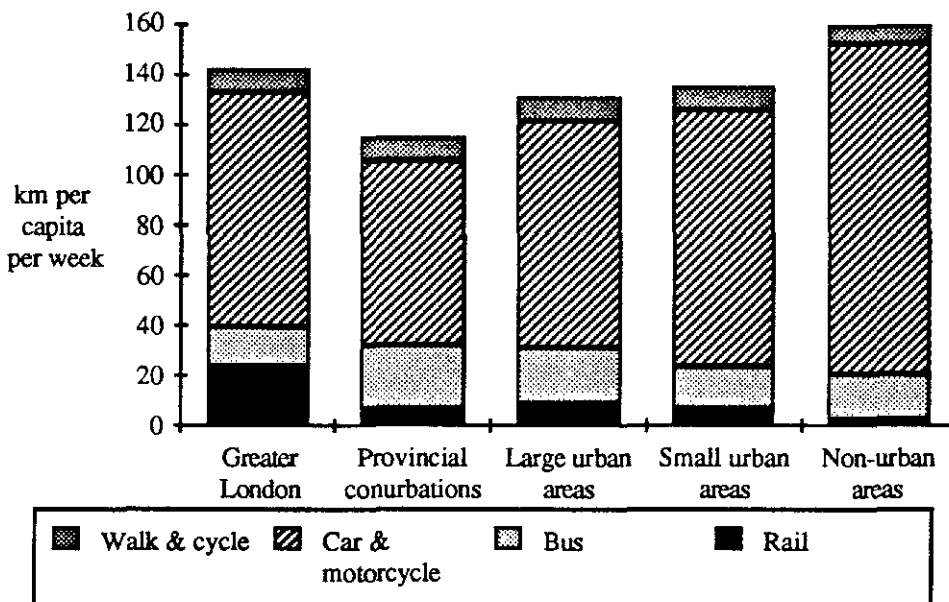
Hughes (1990) present a broad correlation between population density and the percentage of households within close range of a station.

With the exception of Greater London, personal travel decreases with increasing settlement size. Significantly, the *number* of journeys undertaken per person shows very little change.

According to Owens (1986), the influence of settlement pattern upon energy consumption is primarily through travel mode and journey length, rather than through journey frequency.

Moreover, journey length is fairly constant not only across different settlement densities, but also over time. In 2.3.3 it was shown that the number of journeys per person per week increased only marginally in the period 1975-85, whereas the total distance travelled increased by a third.

Figure 2.9 Travel by residents of different settlement sizes, 1972



Source: Maltby et al, 1978.

2.4. The wider view: non-operational energy demand in personal travel

Having identified the factors influencing energy use in the operation of personal travel, it is necessary to examine sources of these gases that are related to the provision of passenger transport but not directly connected with operations. As explained earlier, these include the manufacture and maintenance of vehicles and infrastructure, and account for about one fifth of all energy used in passenger transport.

2.4.1. The manufacture and maintenance of vehicles and components

Within the UK manufacturing sector, the vehicle and transport equipment (VTE) subsector is estimated to be the third largest consumer of energy, with an estimated consumption in 1990 of between 122 and 128 petajoules (PJ).¹ In 1980 the VTE subsector used 59 per cent of all its energy for space-heating its premises (Department of Energy, 1984).

Compared with other manufacturing industries, VTE is not especially energy-intensive. Table 2.5 compares the energy intensity of different subsectors using three different measures. Energy consumption within the VTE subsector is not dominated by any single fuel, but is spread between coal, oil, natural gas and electricity.

Figure 2.10 shows how delivered energy is divided between different fuels according to a Department of Energy forecast for 1990. An estimate has been made (SMMT 1980) of the breakdown of energy consumption in the manufacture of a car. The results are given in Figure 2.11.

Table 2.5 shows that vehicle manufacture is less energy-intensive than other manufacturing subsectors. However, a number of the more energy-intensive industries are related to the transport sector in that they supply the vehicle manufacturing industry with raw materials; but they are further back in the manufacturing process. In particular, the iron and steel industry is among the heaviest users of energy. Howard (1990) estimates the energy requirement of road transport in raw material production, and his results are given in Table 2.6. The energy used in vehicle manufacture is of the same order of magnitude as that used in the production of raw materials for transport.

After a motorised vehicle has been produced, the ongoing process of vehicle maintenance begins. Table 2.6 also gives details of the energy costs of manufacturing and maintaining vehicles in different travel modes.

¹ In first and second place are iron and steel (252 to 284 PJ) and organic chemicals (132 to 148 PJ).

Table 2.5 Energy intensity measures for various manufacturing industries in 1979

Subsector	Energy intensity measures:		
	Energy/net output (MJ/£)	Energy purchases/total purchases (%)	Energy purchases/net output (%)
Iron and steel	237.0	17.7	43.3
Cement	315.0	67.4	44.2
Organic chemicals	165.0	11.1	28.6
Food and drink	25.9	2.8	6.5
Textiles	25.3	5.5	6.3
Metal goods	38.4	7.9	7.6
Vehicle transport equip't	18.7	4.6	5.1
Sector average	36.8	6.9	8.5

Source: Howard, 1990, from Department of Energy, 1984.

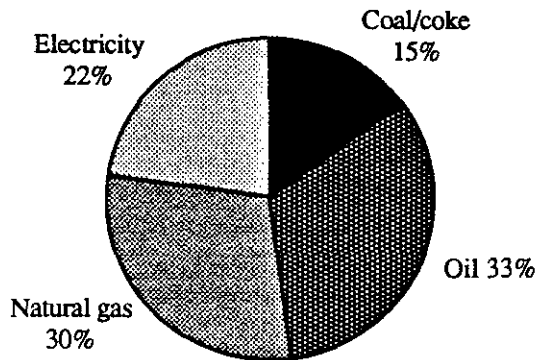
Table 2.6 Energy use for different purposes according to travel mode

	Car		Coach		Train		Aircraft	
	GJ	%	GJ	%	GJ	%	GJ	%
<u>Manufacture</u>								
Raw materials	42.1	46.3	331.2	18.9	8,402.4	15.5	1,396.8	21.9
Manufacture	15.8	17.4	127.8	7.3	2,869.2	5.3	478.8	7.5
<u>Maintenance</u>								
Spare parts	16.6	18.2	88.9	5.1	20,372.4	37.5	748.8	11.7
Tyres	11.5	12.6	75.6	4.3	-	-	1,598.4	25.0
Lubricants	5.0	5.5	113.4	6.5	3,754.8	6.9	-	-
Other	-	-	1,018.1	58.0	18,900.0	34.8	2,160.0	33.8
Total	91.0	100.0	1,755.0	100.0	54,298.8	100.0	6,382.8	100.0

Notes: 'Train' = engine + five cars; 'Aircraft' = Fokker F28.

Source: Zeevenhooven, 1990.

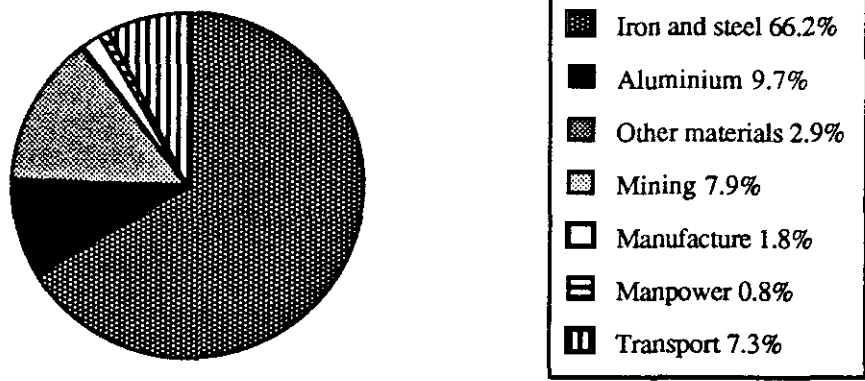
Figure 2.10 Energy consumption in the VTE subsector by fuel



Total: 118 - 133 PJ

Source: Department of Energy, 1984.

Figure 2.11 Energy consumption in the production of a car



Total: 34.0 GJ

Source: SMMT, 1980.

2.4.2. Transport infrastructure

A significant demand for energy relates to the provision and maintenance of transport infrastructure. Zeevenhooven (1990) has estimated the energy costs of building and maintaining road and rail infrastructure in Sweden. He restricts his examination to road, rail and air, and excludes peripheral items such as garages, transport terminals and so on. Table 2.7 shows his results.

Table 2.7 Energy consumption for constructing and maintaining road, rail and air infrastructure

	Road		Rail		Air	
	GJ/km	%	GJ/km	%	GJ/pass.	%
<u>Construction</u>						
Production of raw materials	217.8	32.3	133.2	48.0	0.009	30.0
Building the machines	89.3	13.3	57.6	20.7	0.003	10.0
Driving the machines	16.9	2.5	10.8	3.9	0.001	3.3
<u>Maintenance</u>						
Production of raw materials	331.2	49.2	50.4	18.2	0.017	56.7
Building the machines	15.5	2.3	21.6	7.8	-	-
Driving the machines	2.9	0.4	4.0	0.1	-	-
<u>Total</u>	673.6	100.0	277.6	100.0	0.03	100.0

Source: Zeevenhooven, 1990.

Transport by rail is less energy intensive in terms of infrastructure and maintenance than road transport, as is the case for operational energy demand. Air travel requires very little energy per passenger for infrastructure.

By its nature, the energy used in providing transport infrastructure cannot be clearly divided between passenger and freight operations, as both of these are dependent on it.

2.4.3. Summary

Although most energy consumed by transport is used in the operation of vehicles, the energy demand of peripheral activities, such as the construction and maintenance of vehicles and infrastructure, is important. These categories of energy demand might be particularly important when assessing options for a new transport system, where the choice of mode has

implications for the construction of new infrastructure and the capacity for additional vehicles.

2.5. Energy use and greenhouse emissions

The recent development of passenger transport has been characterised by a sustained increase in passenger mileage by the least energy-efficient of travel modes, the private car and the aircraft (although air travel began as a very small percentage of all travel). The pattern of energy consumption resulting from this trend can be translated into a corresponding volume of 'greenhouse' emissions.

2.5.1. Emissions of CO₂

As noted in Chapter One, CO₂ is the most significant of anthropogenic greenhouse gases. Emissions of CO₂ are directly proportional to net energy consumption, given a particular mix of fuels. Historically the trend towards petroleum fuels away from coal has been advantageous, in terms of both the specific CO₂ emissions of either fuel and the thermal efficiencies of internal combustion (IC) engines compared with steam engines. But the growth in transport demand has greatly outweighed this gain. Today transport derives more than 99 per cent of its energy from petroleum, and CO₂ emissions are rising in proportion to overall energy demand.

Within the category of petroleum, different fuels have slightly varying carbon contents. Diesel, for example, has more carbon by volume than motor spirit, and a greater density; so for each gallon consumed a marginally greater amount of CO₂ is produced.¹

2.5.2. Emissions of other greenhouse gases

The complexity of atmospheric chemistry means that a number of other transport-related gases are implicated, directly or indirectly, in radiative forcing (Walsh, 1990). The picture is further complicated by the different *lifetimes* of various greenhouse gases. The relative importance of different greenhouse gases is dependent on the timescale over which its effect

¹ This effect is usually outweighed by the superior combustion efficiency of diesel engines when compared with spark (petrol) engines, so that on a mile-for-mile basis diesel-engined vehicles produce less CO₂ than their petrol-engined counterparts. In addition, refining losses are lower for diesel than for petrol (Table 2.2).

is measured. Some greenhouse gases have relatively short lifetimes, and the difference between their short and long-term contribution to radiative forcing is considerable (ibid).

The use of CFCs in vehicle air conditioning systems should be mentioned for its direct contribution to greenhouse emissions. This source of CFC emissions is, however, of little significance in the UK, firstly because air conditioning is still a relatively uncommon feature of private cars when compared with countries such as the USA, and secondly because CFCs in general are likely to be eliminated from such applications, in compliance with the Montreal Protocol (see Chapter One).

The role of *carbon monoxide* (CO) should not be overlooked. Although this gas has no direct radiative forcing effect, its reaction with hydroxyl (OH) radicals has the effect of allowing the abundance of other greenhouse gases, such as methane, to increase (Ramanathan, 1988).¹

Transport can also contribute *directly* to emissions of methane, through the release of hydrocarbons (HC) from fuel tanks. Leakage from vehicles running on natural gas also constitutes a potential source of methane emissions, since methane is the main constituent of this fuel. Motor vehicles are thought to contribute around one per cent of overall methane emissions (Department of Energy, 1990).

Although methane emissions are derived primarily from agriculture, mining and landfill activities, a development of natural gas as a transport fuel would be likely to increase the overall output. Mills et al (1991) hold the view that cars running on natural gas will produce more 'CO₂-equivalent' than conventional petroleum-driven vehicles:

Total greenhouse gas emissions are in fact greater for CNG [compressed natural gas] automobiles after including the CO₂ releases from fuel production and related methane and N₂O emissions.

Additionally, high levels of methane in the atmosphere can lead to an increased concentration of water vapour, produced when the gas is oxidised (Ramanathan, 1988).

Mention should also be made of the contribution of nitrogen oxide (NO_x) emissions to global warming. One of the oxides of nitrogen, nitrous oxide (N₂O), is a greenhouse gas, though the others also contribute indirectly to global warming when they react in sunlight with hydrocarbons to form tropospheric ozone.

¹ Methane is normally removed from the atmosphere through a reaction with OH, so if the abundance of OH becomes less, methane proliferates.

Although N₂O is responsible for only six per cent of greenhouse warming, transport is the largest producer of this gas in the UK.¹ Table 2.8 gives details of transport's emissions of CO, NO_x and hydrocarbons in 1989. The figures refer to both freight and passenger operations, as no disaggregated data are available.

Table 2.8 Transport's emission of regulated pollutants in 1989

Pollutant	Emissions from transport (thousand tonnes)	% of UK total
Nitrogen oxides (NO _x)	1,330	49
Carbon monoxide (CO)	5,763	88
Hydrocarbons (HC) (excluding methane)	770	37

Note: figures exclude air and water transport, whose contributions are small.
Source: Department of Transport, 1991a.

Dallemagne (1990) has catalogued the various Directives introduced by the European Commission since 1970 relating to emissions of regulated pollutants (NO_x, CO and HC) from cars sold in member states. Before June 1989, it was expected that small and medium cars would be able to meet the emissions requirements using a combination of lean-burn combustion and simple oxidation catalysts. The legislation for small cars that was introduced in June 1989, however, was more stringent than this, and effectively required all new cars to be fitted with three-way catalysts. Table 2.9 summarises the emissions requirements laid down by the EC.

It appears likely that the distinction between different engine capacities will shortly be removed from the emissions legislation, with the introduction of a new test procedure. Effectively, the permitted level of pollutants for all cars would be lowered to the level currently applicable to small cars, or possibly lower (*ibid*).

The latest Directive marks the end of much uncertainty on the part of motor manufacturers on what the favoured course of action would be. Previously, some manufacturers had hoped that lean-burn engines would be capable of satisfying European legislation (Boehmer-Christiansen, 1990). In practical terms the ruling means that all new cars must be fitted with

¹ It is worth noting in passing the influence of altitude on aircraft emissions. According to the European Commission (1992), "It is thought that the impact of 'greenhouse gases', particularly NO_x, is much greater [in the mid to upper troposphere] than if produced at ground level."

three-way catalytic converters by the beginning of 1993, and research into lean-burn technology has been cut back as a result.

Table 2.9 EC limit values for regulated pollutants

Engine size	Limit value (grams per test)	Implementation date:	
		new models	old models
<u>Directive 88/76/EEC:</u>			
Over 2.0 litre	CO: 25 HC + NOx: 6.5 NOx: 3.5	1 October 1988	1 October 1989
1.4 - 2.0 litre	CO: 30 HC + NOx: 8	1 October 1991	1 October 1993
<u>Directive 89/458/EEC:</u>			
Less than 1.4 litre	CO: 19	1 July 1992	31 December 1992

Source: Dallemagne, 1991.

In terms of greenhouse forcing, a reduction in emissions of the regulated pollutants will have a beneficial effect. However, a number of factors will act against this improvement:

- ❑ Whilst individual vehicles will become less polluting, aggregate emissions of these compounds will increase in proportion to total traffic volumes. An increase in vehicle mileage may therefore diminish the benefits of exhaust filtering (Holman et al, 1990);
- ❑ In addition, it is widely accepted that catalytic converters do not operate at full efficiency in cold conditions. This implies that in cold climates the performance of catalysts will tend to suffer (Workhouse, 1991), and that catalytic converters will not become effective until some time after an engine has been cold-started.¹ Thus short car journeys are significantly more polluting, per kilometre, than longer ones. If travel patterns continue to

¹ There is evidence that the standard EC test fails to take full account of cold-starting, as it takes place with an ambient temperature of 25°C. The investigation by Workhouse (1991) has shown that when the EC test cycle is performed at typical European air temperatures, catalyst-equipped cars produce significantly greater levels of all three regulated pollutants than the official test results suggest.

change in favour of an increased proportion of short journeys, it is likely that the emission of regulated pollutants will increase accordingly;

- ❑ Direct emissions of N₂O, a greenhouse gas, have been shown to be between five and eight times greater from cars fitted with catalytic converters than from cars without. However, *indirect* emissions of N₂O are less from cars with catalysts, because the NO_x from which they are derived is largely eliminated by the catalyst. The net effect is unclear, and further research is needed to evaluate whether N₂O emissions are greater from catalysed or uncatalysed exhausts (Dallemane, 1990);
- ❑ Three-way catalytic converters are generally regarded as having a detrimental effect on vehicle fuel economy. For example, the official urban fuel consumption figures for a 1.4-litre Ford Escort are 8.9 l/100km for the conventional model and 10.0 l/100km mpg for the catalyst-equipped version - a shortfall of 12 per cent. If vehicles are using more fuel per kilometre as a result of being fitted with a catalyst, there will be a resultant increase in CO₂ emissions;
- ❑ Finally, and least significantly, the appearance of *unleaded* petrol in Britain, introduced as a necessary forerunner to the three-way catalytic converter, will have a slightly detrimental effect upon fuel economy, because of the lower octane rating of unleaded fuel. All new cars in Britain must now be able to run on unleaded, and the use of leaded fuel is expected to decline further as new cars replace old ones. However, future fuel economy will be influenced more by other vehicle technologies than by the type of fuel on which cars are operated.

It has been argued that lean-burn technology is a more satisfactory means of controlling emissions than catalytic converters, because it generally leads to an improvement, rather than a penalty, in fuel economy. The problem of cold-starting in catalyst-equipped vehicles can be partially solved by pre-heating the catalyst. Alternatively, the entire engine may be pre-heated. A technique developed by Volkswagen involves storing the engine's heat in a highly-insulated container filled with a fluid of high energy density, and then using the stored heat to warm the engine next time the car is used (Barrie, 1990).

If lean burn engines do in future prove capable of meeting the EC requirements for exhaust emissions, then manufacturers will be in a position to eliminate catalysts from their cars. Among the benefits will be a reduction in fuel consumption and CO₂ emissions.

In the meantime, the progressive introduction of catalytic converters to Britain's car fleet will, on an individual car basis, reduce the emissions of certain greenhouse gases, as well as gases that contribute indirectly to radiative forcing. Emissions of carbon dioxide from each

vehicle will marginally increase, to an extent that could be counteracted by improvements in other areas of vehicle technology. The production of 'regulated' pollutants will not be entirely eliminated by catalysts, and is likely to rise if traffic growth continues (Holman et al, 1990).

This study will not attempt to evaluate the effects of different policies on all greenhouse gases; instead, the focus will be on CO₂. With a few exceptions, reductions in the emission of CO₂ are generally accompanied by reduced emissions of other greenhouse gases, simply because less fossil fuel is being consumed. To some extent CO₂ can therefore be regarded as a 'surrogate' for these other gases.

Chapter Three

ASPECTS OF FUEL CONSUMPTION IN MOTORISED TRAVEL

3 ASPECTS OF FUEL CONSUMPTION IN MOTORISED TRAVEL

“The ‘cleaner’ the car, the more fuel it uses;
The more fuel it uses, the more carbon dioxide;
The more carbon dioxide, the more heat.”

Heathcote Williams, *Autogeddon*

3.1. The influence of fuel consumption on greenhouse emissions

The preceding chapter described the ways in which transport in its wider context contributes to greenhouse emissions. A key factor influencing overall CO₂ emissions was shown to be specific energy consumption (SEC), or the amount of energy consumed by a person to cover a given distance. SEC is a function of two variables: firstly the occupancy of the vehicle; and secondly its fuel consumption, measured in MJ/vkm.

Figure 2.6 showed how SEC has changed since 1970 for different modes. Advances in vehicle technology have, by their nature, facilitated improvements in vehicle fuel economy. But in some cases, these improvements have been accompanied by declining load factors, with the two trends to some extent counteracting one another. In this respect the importance of measuring energy consumption *per person carried*, or SEC, is crucial. In the airline industry, for example, there has been an ongoing trend towards larger and more efficient aircraft. Whilst these consume more fuel per kilometre than their predecessors, their energy consumption per passenger kilometre is less.

The effect of an ongoing increase in travel volume (see previous chapter) can be offset by an improvement in specific energy consumption (SEC). This chapter will focus on the factors that influence fuel economy in the motorised travel modes.¹

¹ The term ‘fuel consumption’ is often interchanged with ‘fuel economy’. Although both terms are acceptable, it should be noted that one is the inverse of the other.

3.1.1. Note on non-motorised modes

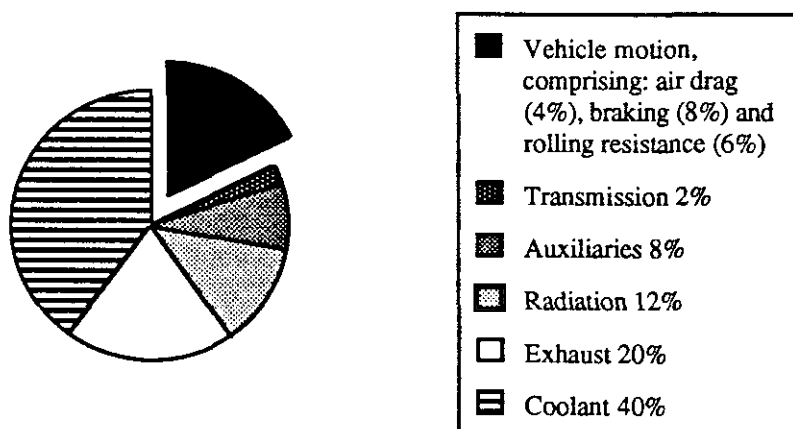
This chapter will examine SEC in the principal motorised modes, namely cars, buses and coaches, trains, and aircraft. No consideration is made of the energy consumption of the non-motorised modes, walking and cycling. The energy efficiency of these human-powered travel modes can to some extent be improved, through the development of more efficient machinery and infrastructure. But the benefits of such advances are not considered to have a direct effect on greenhouse emissions, being restricted to an improvement in travel quality for the user. Instead, they offer the potential for reduced emissions by encouraging modal changes from less energy-efficient forms of transport.

3.2. Fuel economy in private cars

3.2.1. Energy losses in cars

In order to understand the nature of energy use in cars, it is helpful to divide a car's energy consumption into different 'sinks'. Figure 3.1 breaks down energy consumption into various categories for a typical vehicle covering a combination of driving patterns, and shows that typically only 18 per cent of a car's energy consumption is used in providing motion. The remaining 82 per cent is lost either as waste heat, generated by frictional forces between moving parts, or as a result of the thermodynamic limitations associated with heat engines (Department of Energy, 1981).

Figure 3.1 Energy losses in a typical car journey



Source: OECD, 1982.

3.2.2. Performance versus fuel economy

The resources invested in the development of vehicle efficiency by motor manufacturers are very great, and the results of their research have led to considerable advances in areas such as engine and transmission efficiency, materials technology and aerodynamics.

Improved vehicle efficiency can be used in two ways:

- ❑ to improve the fuel economy of the vehicle, by reducing its engine capacity, whilst leaving its performance unchanged; or
- ❑ to increase the performance of the vehicle whilst its engine capacity and fuel economy are unchanged.

With the exception of the periods of short-lived frugality that followed sudden oil price rises, the second of these has been the dominant effect. In the presence of low fuel prices, energy-efficiency technologies have generally been used to produce more powerful cars whose fuel economy is virtually unchanged. An indication of this effect can be found in car advertising material, which commonly emphasizes performance in preference to fuel economy.¹

3.2.3. The company car factor

Another important influence on car fuel consumption in Britain is the 'company car factor'. The provision of company cars for the use of employees is a popular practice among British firms, and Britain has the highest proportion of company-financed cars in the world. A car is regarded as a form of income-in-kind on which a reduced rate of tax is payable, and as such provides an economic benefit to companies (Potter, 1991a).

In 1990, 52 per cent of new cars in Britain were registered in the name of a company. Allowing for cars bought by companies and registered in the name of the driver (a practice designed to increase resale value), the proportion of cars bought by companies is over 70 per cent (ibid).

The 'company car factor' has important implications for emissions of CO₂, because company cars tend to have larger engine capacities than privately-purchased cars, and to be driven further. Details of these effects are given below.

¹ Until recently the most economical car available on the British market, and probably worldwide, was the Daihatsu Charade Diesel. Little or no mention was made of this feature in Daihatsu's advertising material or in motor show displays. Only recently has Daihatsu begun to use fuel economy as a marketing tool.

The various factors influencing car fuel consumption, divided into vehicle effects and operational effects, are listed below, together with estimates of their effect on fuel consumption. All of them have to some degree been exploited to obtain greater performance, as outlined above.

3.2.4. The measurement of car fuel economy

In the UK, and throughout the EC, car manufacturers are required to submit all new models to a series of tests to establish their average fuel economy. The fuel economy data comprise three figures, corresponding to (i) an urban cycle, (ii) constant 90 km/h driving, and (iii) constant 120 km/h driving.

The figures are intended as a guide for purchasers of new cars who wish to compare the fuel economy of different models. As an indicator of real-life fuel economy, however, they are less reliable. Average fuel economy has been calculated for each year since 1978 by the Department of Transport using a sales-weighted average of the official data, and this is presented in Figure 3.2. The graph also shows the same quantity calculated using an 'empirical' method, whereby the total consumption of motor spirit for each year is divided into the annual car mileage.

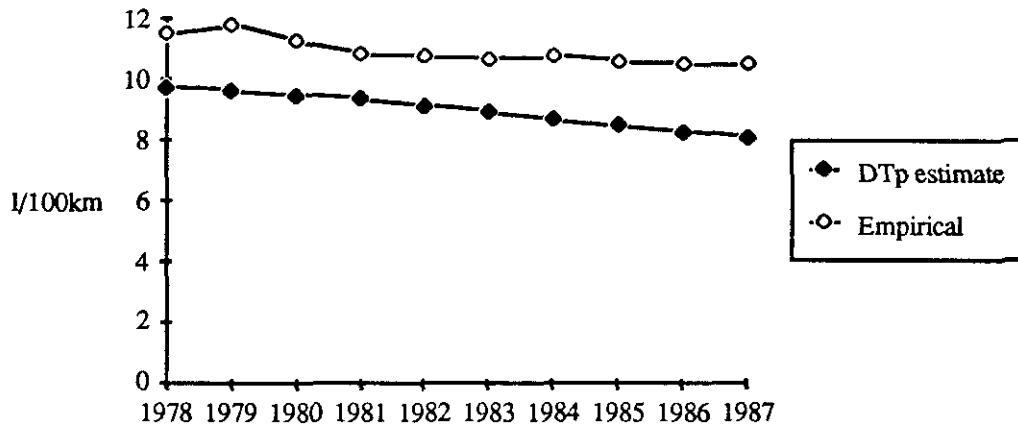
An average discrepancy of 22 per cent exists between the fuel economy derived from the official test results and that based on the aggregate volume of fuel actually used. The difference increased from 18 per cent in 1978 to 30 per cent in 1988. The presence of this 'mpg gap' is attributable to the omission of a number of factors from the official fuel consumption tests. The Department acknowledges the shortcomings of the vehicle test procedure:

The standard tests ... cannot be fully representative of real-life driving conditions.... The fuel consumption achieved on the road will not necessarily accord with the official test results.

(Department of Transport, 1990).

These differences are important in terms of transport policy. Using the official measure, fuel economy improved by 17 per cent in the period 1978-87. But the *actual* improvement was much smaller - only nine per cent.

Figure 3.2 'Official' and 'empirical' estimates of average car fuel economy



Sources: National Audit Office, 1989 and Department of Transport, 1991a.

3.2.5. Vehicle effects and operational effects

Vehicle fuel economy is determined by many factors acting together. Independent of the design of the vehicle, aspects of vehicle usage can have a significant effect on average fuel consumption.

Factors influencing fuel consumption can be subdivided into *vehicle effects* and *operational effects*. Vehicle effects may be defined as the aspects of vehicle design that influence its fuel economy rating, including engine size, aerodynamics and body weight. Operational effects are the details of its usage, such as the type of roads on which it is normally driven, the manner in which it is driven and the care with which it is maintained.

VEHICLE EFFECTS

3.2.6. Car engine design

Car engines in Britain may be divided into two types: petrol (spark ignition) engines and diesel (compression ignition) engines.¹ Diesels are less powerful for a given engine capacity than petrol engines: the power rating for a diesel engine is between 20 and 38 kilowatts per litre, compared with 30 to 55 kW/litre for a petrol engine (Department of Energy, 1989).

However, diesel engines are more economical than petrol engines when cars of equivalent performance are compared. A study undertaken by the Transport and Road Research Laboratory (Redsell et al, 1988) has shown that a diesel-engined Vauxhall Cavalier is between four and 22 per cent more economical than its petrol-engined equivalent.

The poorer fuel economy of petrol engines can be related to three characteristics:

- ❑ Energy efficiency under partly-loaded conditions is poor in petrol engines because output is controlled by throttling the fuel/air intake;
- ❑ The ratio of fuel to air in petrol engines is held constant at approximately the stoichiometric value (the ratio of whereby fuel and oxygen are present in the precise quantities for complete combustion to take place, normally around 15:1). In many circumstances better fuel economy can be achieved using a weak fuel mixture;
- ❑ The compression ratio of petrol engines, which should be maximised for best fuel efficiency, is limited by the onset of spontaneous ignition ('knocking'). To raise the compression ratio requires an increase in the octane number of the fuel, which is influenced by refinery processing and the presence of anti-knock additives containing lead compounds. Legislation requires that all new cars in the UK run on unleaded fuel, so the second route is not feasible.

In diesel engines the fuel is ignited not by a spark but by the compression of fuel within the combustion chamber. The superior fuel economy of diesel engines is related to:

- ❑ increased compression ratio and weaker fuel-air mixture;
- ❑ the control of power output using fuel supply metering, rather than throttling with a fixed mixture.

¹ In 1990, 19,739,000 cars with petrol or diesel engines were registered in Great Britain. No electrically-powered cars are recorded, but some 5,000 were powered by 'other' sources (steam, gas, petrol/gas). Source: Department of Transport, 1991a.

Diesel engines create more noise and vibration than spark engines, as a result of the greater compression ratio, and are also heavier and more expensive.

Traditionally diesel engines fitted to cars have been of the *indirect injection* type. However, an increasing number of manufacturers are switching to *direct injection* because of its enhanced efficiency, although noise and emissions tend to be greater.

A number of technologies exist for enhancing the energy efficiency of petrol and diesel engines. As explained above, an increase in efficiency may be used to enhance fuel economy, or else to increase performance whilst maintaining the same fuel economy. *Turbocharging* is a technique whereby exhaust gases are used to drive a fan which physically impels the fuel-air mixture into the cylinder. The result is a denser mixture, and a greater power to weight ratio. A turbocharger may be used in conjunction with *aftercooling*, whereby the air from the turbocharger is cooled using a heat exchanger so that more air is drawn into the engine at the induction stroke.

Intercooling is the term given to the cooling of the air-fuel mixture before it enters the cylinder: as with turbocharging, this has the effect of increasing the density of the mixture, which has a beneficial effect on engine efficiency.

A study by Pearce et al (1980) examines the fuel consumption of diesel and petrol cars under cold-start conditions. The loss of fuel efficiency associated with cold running is shown to be less significant in a diesel engine. In addition, the diesel engine takes less time to reach its full operating temperature. In fact the 'mpg gap' between actual and official fuel consumption is smaller for diesels than for petrol engines, because diesel engines are less susceptible to many of the effects that cause fuel economy to fall below the official figures.

3.2.7. Car engine capacity

It has been shown that fuel consumption is dependent on the type of engine fitted to a vehicle. It is, of course, strongly influenced by the *capacity* of the engine, or the total volume swept by the pistons inside the cylinders. In general, the bigger the engine, the higher the fuel consumption.

Table 3.1 lists the average fuel economies of six engine size categories. A car of capacity 1.0 litre or less uses a little over half the fuel of a 2.0-litre car to cover the same distance.

The engine size of company cars is on average 190cc larger than that of non-company cars. Fergusson (1990) has estimated that this increased engine size is responsible for over three per cent of CO₂ emissions from cars. In addition, company drivers travel an average of 2,700 miles per year more than private motorists, and both effects together are responsible for five per cent of CO₂ emissions from cars.

3.2.8. Vehicle weight

Significant fuel savings are possible through a reduction in vehicle weight, achieved principally by switching to lighter materials. The principal components of a car's mass are the body (28 per cent), the engine and transmission (21 per cent) and the trim, including glass (16 per cent). The use of aluminium offers a reduction of up to 30 per cent in vehicle weight. The fuel saving from weight reduction is between three and five per cent for every 10 per cent cut in weight, although this may depend on changes in engine and transmission characteristics (Department of Energy, 1989).

Table 3.1 Average fuel economy of different engine sizes, 1986

Vehicle category		Average fuel economy (l/100km)
Petrol-engined:		
Over	Not over	
	1000 cc	7.6
1000	1200 cc	8.3
1200	1500 cc	8.9
1500	1800 cc	9.8
1800	2000 cc	10.6
2000 cc		13.7
Diesel-engined:		
Over	Not over	
	1800cc	6.4
2000cc		7.7

Source: Department of Energy, 1989.

Table 3.2 lists the materials by weight that are found in a typical small car. Advances in materials technology are likely to reduce the overall mass of iron and steel used in cars, in favour of non-ferrous metals and plastics. It is likely that aluminium will play an increasing role in vehicle manufacture, and could represent as much as 20 per cent of a car's weight by the year 2000. Pressure to produce lightweight cars has been experienced by Japanese manufacturers, whose largest market, the USA, demands strict fuel economy and emissions standards (Gooding, 1991).

Table 3.2 Materials used in the Austin Metro

<u>Material</u>	<u>Mass (kg)</u>	<u>% of total</u>
Steel	422.4	59
Cast iron	110.0	15
Aluminium alloys	20.5	3
Copper and its alloys	4.5	1
Zinc alloys	1.5	-
Lead alloys	9.2	1
Other metals	1.0	-
Rubber	35.0	5
Plastics	35.0	5
Glass	30.0	4
Other nonmetallic	41.0	6
Total	710.1	100.0

Source: Alexander and Street, 1989.

The trend towards lighter cars is liable to be offset, however, by an increase in the amount of ancillary equipment, and in particular safety features. Tests conducted at the Transport and Road Research Laboratory (1987) suggest that vehicle weight could be increased by around three per cent as a result of design features aimed at limiting the risk associated with vehicle collisions.

The weight of persons and luggage carried by a car also influences its fuel consumption. There are two reasons for this:

- the energy required to accelerate the vehicle increases with weight, since kinetic energy is directly proportional to mass;
- Unless tyre pressures are readjusted, the rolling resistance of the vehicle increases when extra weight is added. This is because the cyclical compression of tyres in motion is not perfectly elastic, and some energy is absorbed in the form of heat.

The Department of Energy (1989) estimates that each passenger of average weight is responsible for a three per cent increase in fuel consumption on main roads, and four per cent in urban driving conditions.

3.2.9. Vehicle transmissions

The transmission system is the assembly that carries power from the engine to the wheels, through some form of gearing. The system of gears is the most critical component in terms of energy losses. Conventional gearboxes offer little prospect for energy saving: the principal areas in which improvements may be made are in refining the mechanical efficiency and in optimising the gear ratios so that engine speed is best matched to driving conditions. A practical application of this principle has been the trend in recent years from four-speed to five-speed gearboxes: the extra gear allows the engine to run more slowly, and more economically, in high-speed driving.

Beyond conventional designs lies the concept of *continuously-variable transmission* (CVT), in which the set of discrete gear ratios is replaced by an infinitely-variable system. In this way the engine speed can be maintained at its most efficient level regardless of vehicle speed. Such transmissions were fitted to Daf cars in the 1970s, and have recently been introduced in some Subaru vehicles. The fuel saving resulting from the use of CVT is as much as 20 per cent compared with a conventional four-speed gearbox (Department of Energy, 1989).

More advanced systems such as *automated manual transmission* have been developed, in which discrete gear changes are retained but controlled by electronics. Fuel savings of up to 15 per cent have been claimed for these devices, compared with conventional four-speed gearboxes (ibid).

3.2.10. Vehicle aerodynamics

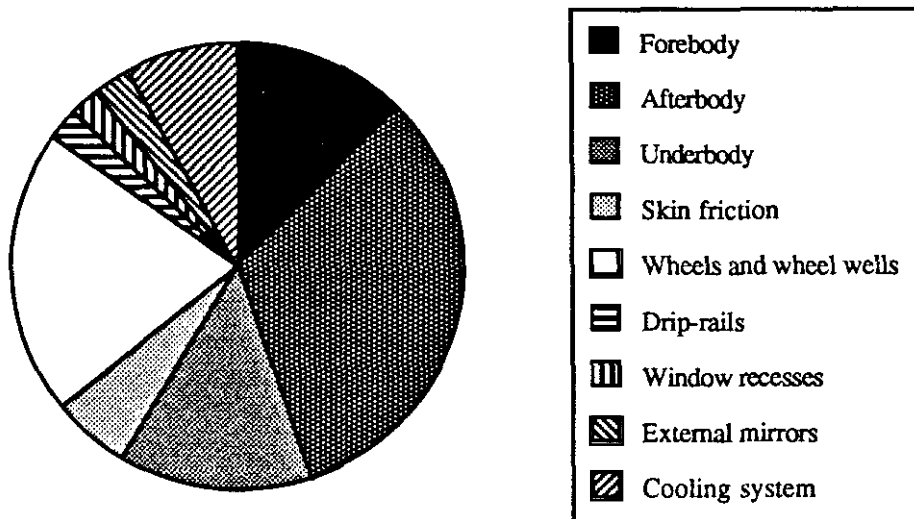
Aerodynamic drag constitutes a significant loss of energy in private cars, particularly in high-speed conditions. It is dependent on the speed, frontal area and drag coefficient of the vehicle, according to the equation

$$D = 0.5 C_d \rho S v^2$$

where D is the drag force, C_d is the coefficient of drag, ρ is the air density, S is the vehicle frontal area and v is the speed (measured as the air velocity in a wind tunnel). Vehicles currently in use have an average drag coefficient of around 0.38.

Figure 3.3 breaks down the drag coefficient of a typical car into components, showing how various aspects of car design contribute to the overall drag coefficient C_d .

Figure 3.3 Contributions to overall drag coefficient in a typical car



Source: Carr, 1983.

3.2.11. Emission controls and electronic engine management

The effect of catalytic converters on exhaust pollution was discussed in the previous chapter. Their effect on fuel consumption is generally regarded to be moderately detrimental. By contrast, the lean-burn approach to emission controls generally entails some improvement in fuel economy (Workhouse, 1991). Lean burn engines, when fitted with no additional emission control equipment, consume up to 14 per cent less fuel than an unregulated engine. However, lean-burn has been rejected by the EC because it was not considered capable of achieving sufficient reductions in emissions of the regulated pollutants.

Electronic engine management systems are becoming increasingly common on production cars as part of the exhaust-cleaning operation. The most advanced of these receive data from various sensors in the engine, and use them to control the running of the engine. The system covers such aspects as ignition timing, fuel injection, exhaust emissions, and even suspension and transmission control.

Figures are not available for the specific improvement in fuel economy associated with such systems, but electronic management offers considerable potential for fuel conservation through improved efficiency.

3.2.12. Vehicle maintenance

As a vehicle ages, worn components can begin to worsen fuel economy. Sources of inefficiency in the engine include ignition timing, carburation, slack belts and soiled filters.

Since November 1991, the annual vehicle test required by the Department of Transport has included a check of exhaust emissions. It is likely that this will lead to an improvement in the engine tuning of many older vehicles, with a resulting increase in fuel economy.

Inefficiency can be caused in other areas of the vehicle too, such as the following (Department of Energy, 1989):

- ❑ Misaligned wheels can compromise fuel consumption by increasing the rolling resistance of the tyres. Penalties of two or three per cent in fuel economy can result from misalignments of as little as 2mm;
- ❑ Underinflated tyres lead to increased rolling resistance and reduced fuel economy. An error of $\pm 200 \text{ g/cm}^2$ in inflation pressure can lead to a one per cent loss of fuel economy;
- ❑ Poorly adjusted brakes can increase fuel consumption by up to four per cent;
- ❑ Enhanced fuel economy is associated with larger wheels and radial-ply tyres. The latter can improve fuel economy by around four per cent. Inefficient cross-ply tyres are largely obsolete nowadays;
- ❑ Engine oils containing friction-reducing agents can cut fuel consumption by two or three per cent.

The Department of Energy (op. cit.) points out that most cars are unlikely to be at the 'worst limit' of these variables, and notes that these aspects of car maintenance are largely independent and can therefore be considered additive in their effect.

3.2.13. Vehicle accessories

The fuel consumption of a vehicle can also be affected by the fitting of auxiliary equipment by the owner. Some accessories may affect the aerodynamics, as with roof racks, mirrors and body styling; a roof rack increases the fuel consumption of a vehicle by between seven and 40 per cent at speeds between 90 and 120 km/h. Alternatively, the fitting of ancillary equipment may impose an extra load on the car's power output, as in the case of lamps, air conditioning and power-assisted steering. Typically the electrical system has an efficiency of no more than 10 per cent, so the electrical demand is particularly great (Department of Energy, 1989).

OPERATIONAL EFFECTS

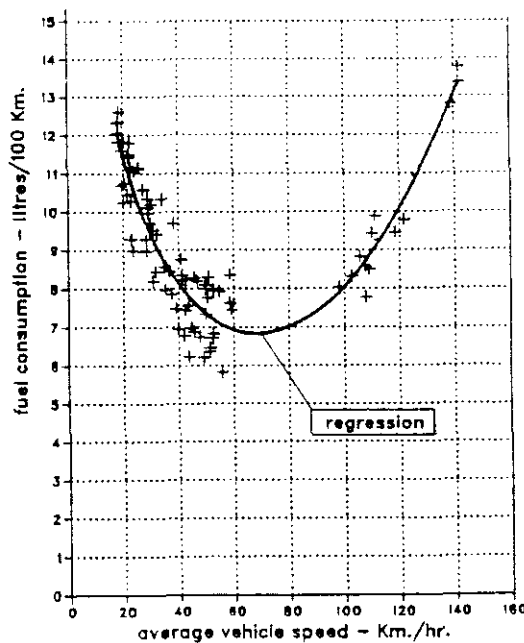
3.2.14. Driving style

The manner in which a car is driven can have a considerable influence on its fuel consumption. Of particular importance is the rate of acceleration and deceleration, as well as overall speed. In a comparison of different drivers in real-life road conditions (Redsell et al, 1988) it was found that an 'expert' driver could return considerably better fuel economy than the group average. In urban, suburban and motorway tests, the 'expert' was able to consume 9, 10 and 24 per cent less fuel respectively than the rest of the group.

Figure 3.4 illustrates the effect of speed on average fuel economy. At low speeds, poor fuel economy is observed as a result of frequent stops and starts, whilst at the high-speed end of the scale fuel economy deteriorates as a result of the increased aerodynamic drag force.

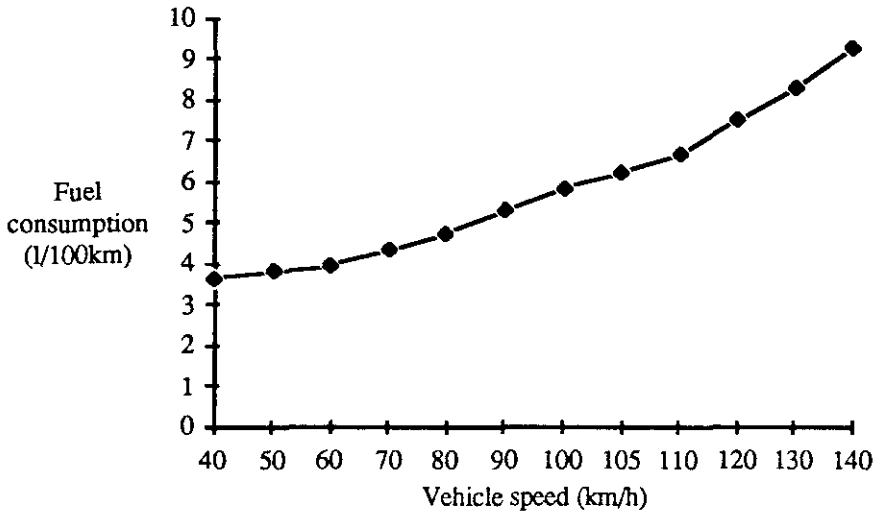
Figure 3.5 shows the results from a similar test performed at *constant* speed. The fundamentally different shape of the graph reveals an optimum level of fuel economy at very low speed. Taken together, these graphs verify that the poor fuel economy normally associated with low speeds is mainly the result of the uneven conditions prevalent in congested driving. Low speed *per se* is not uneconomical, as Figure 3.5 illustrates.

Figure 3.4 The effect of speed on fuel economy (average speeds)



Source: Redsell et al, 1988.

Figure 3.5 The effect of speed on fuel economy (constant speeds)



Source: Ross, 1990.

3.2.15. Type of journey

The type of driving to which a vehicle is subjected is dependent not only on the behaviour of the driver but also on the nature of the journey being undertaken. In particular, short car journeys are prone to poor levels of fuel economy because a large volume of such mileage is covered with a cold engine. More than 60 per cent of car journeys in Britain are less than 8 km in length (Department of Transport, 1988), of which a considerable number are made 'from cold'. It has been shown that an average car typically takes 11 km to 'warm up' fully. During the first few minutes of warm-up, a car may use two to three times more fuel per kilometre than it would when warm (Pearce and Waters, 1980).

As noted earlier, diesel-engined cars are less susceptible to this effect than cars with petrol engines. Diesel engines take less time to warm up from cold (Pearce and Waters, 1980), and are more efficient in the low engine load conditions associated with short, urban trips.

Another factor linking short journeys to poor fuel economy is the prevalence of low speeds and frequent stops in this type of journey.

3.2.16. Traffic management

Traffic management systems have the potential to enhance the fuel economy of road vehicles, by encouraging traffic to maintain economical patterns of flow. In urban areas this involves reducing congestion, so that vehicles can move more freely, and cutting the number of stops. On principal routes, it may involve speed limits to smooth traffic flows.

A central element of traffic management theory relates to the design of junctions. By varying the priority given to a traffic flow, delays at traffic signals can be minimised. An urban traffic control system known as SCOOT (split cycle time and offset optimisation technique) monitors traffic flow conditions and controls traffic signals accordingly, using a computer model of the road network. Over 40 SCOOT systems are in use throughout Britain.

Another example of traffic management technology that can enhance fuel economy is the 'Wolfsburg Wave' information system. The purpose of this is:

... to supply drivers in specially equipped vehicles with a steady flow of information about their relative position with respect to the green period of the next traffic signal, so that they are able to pass through the intersection while the signal stage is still "green" by choosing the appropriate speed.

(Hoffman and Zimdahl, 1988)

Tests on cars equipped with the system have shown that fuel savings of up to six per cent can be achieved, together with appreciable reductions in the number of stops.

Further experimentation with fuel-efficiency technologies has been made possible under PROMETHEUS (Programme of a European Transport System with Highest Efficiency and Unprecedented Safety), undertaken by European car manufacturers.

Traffic calming is another form of traffic management, using techniques developed on the continent. It is based on the principle of slowing down traffic in commercial or residential areas, in order to reduce its impact on pedestrians, cyclists and people using the street for other purposes. Measures include speed humps, chicanes, raised surfaces and 'gateways'. A fuller discussion of traffic calming appears in Chapter Five.

The relationship between traffic calming and fuel consumption is a complex one. When a vehicle is slowed down by calming measures, it may consume more fuel as a result of the obstacles that it has to negotiate. On the other hand, it may use less as a result of the reduction in speed. To complicate matters further, an important effect of traffic calming is to reduce the number of vehicles using a particular street, by encouraging drivers to use alternative routes. It is not clear whether this leads to a better or worse level of fuel economy, because traffic on the alternative route may be either congested or free-flowing. It appears that no clear rules can be established, and that the effect on fuel consumption

depends on the individual circumstances of a particular traffic-calming scheme. Further research on this question would be useful.

3.2.17. Weather conditions

Another driving effect is the influence of ambient conditions, and temperature in particular. The Department of Energy (1989) estimates overall "that fuel consumption is some 10 to 15 per cent greater in winter than in summer". Contributory factors are given as lower engine operating temperature, greater use of auxiliary equipment (heating and lighting) and increased aerodynamic drag as a result of greater air density.

The contribution of weather-related equipment alone (heater, headlamps, wipers and rear window heater) is estimated to be nine per cent. The use of lubricants whose viscosity does not vary much with temperature can reduce energy losses associated with winter driving.

3.3. Fuel economy in buses and coaches

Tables 3.3 and 3.4 give details of the comparative fuel economy of different types of public service vehicle (PSV) in various operating conditions. The final column of Table 3.3 gives a 'traffic weighted' figure, which approximates to the overall fuel economy for each vehicle type.

Table 3.3 Public service vehicle fuel consumption				
Vehicle type	Fuel consumption (l/100km)			Traffic-weighted
	Urban	Suburban	Long-distance	
<u>Petrol-engined:</u>				
12 seat	14.1-16.9	12.0-16.0	-	14.5
20 seat	15.7-24.2	14.1-19.3	-	18.8
<u>Diesel-engined:</u>				
Single-deck	26.7-32.3	19.8-29.3	26.9-33.5	28.5
Double-deck	28.3-50.6	24.6-37.7	-	36.5

Source: Department of Energy, 1989.

Table 3.4 Specific energy consumption of buses and coaches (1986)

Vehicle and journey type	Seating capacity	% vehicle occupancy	SEC (MJ/pkm)
Minibus, suburban	15	25 - 50	0.8 - 1.6
Single-deck coach, suburban	33	25 - 50	0.6 - 1.2
Single-deck coach, motorway	50	25 - 50	0.5 - 1.0
Double-deck bus, city centre	75	50 - 75	0.3 - 0.4
Double-deck bus, suburban	75	25 - 50	0.5 - 0.9

Source: Department of Energy, 1989.

It has been shown that typically only 18 per cent of the energy used by a car is associated with useful work, the remaining 82 per cent being accounted for by thermodynamic and mechanical losses. A similar figure applies to buses and coaches (Department of Energy, 1989).

3.3.1. Operating conditions

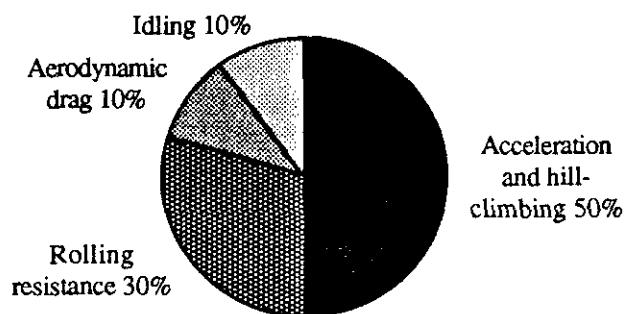
In urban conditions, bus travel is characterised by low speeds with frequent stopping and starting. The Department of Energy (1989) estimates that urban buses stop on average every 400 yards, and have average speeds of 18 to 22 km/h. At these speeds, aerodynamic losses are small compared with the energy used in accelerating the vehicle and in overcoming rolling resistance whilst in motion. Figure 3.6 gives an estimate of how the useful work of an urban bus is divided between various aspects of operation.

In other forms of operation, energy losses can be significantly different. In rural and express services, stops are much less frequent and average speeds are greater. Aerodynamic drag becomes far more significant, accounting for 60 per cent of energy consumption at 100 km/h. The remaining 40 per cent is accounted for by rolling resistance alone, since 'acceleration' and 'idling' are not applicable.

The extreme difference between these two types of operation means that buses cannot be designed for optimum fuel economy; instead, a compromise is made between the conflicting

demands of a low-speed urban bus and an aerodynamically-shaped vehicle for use in high-speed operations.

Figure 3.6 Use of energy in the operation of an urban bus



Note: these figures refer to useful work, which constitutes typically 20 per cent of the total energy consumed by a vehicle (see Figure 3.1). Source: Gotz, 1983.

3.3.2. Vehicle effects and operational effects

As with private cars, factors that influence the fuel consumption of buses and coaches may be categorised into vehicle effects and operational effects. These factors are described below.

VEHICLE EFFECTS

3.3.3. Vehicle design

A conflict exists between design features aimed at maximising fuel economy and those satisfying other criteria. To minimise energy use, a PSV should have low mass, a good aerodynamic shape and small ancillary power demand for lighting, air conditioning and so on. But these characteristics may be in conflict with considerations of safety, passenger comfort and operating convenience. The design of a PSV may therefore be seen as a compromise between a number of requirements.

3.3.4. Bus engine design

As with car engines, new technologies offer substantial fuel savings in PSV engines. Turbocharging, intercooling and optimised fuel injection are some of the areas of potential, as are thermostatic fans and radiator shutters. Additionally, there is speculative evidence that energy savings can be achieved through the use of fuel additives, though the effect is not proven.

Many new PSVs are equipped with turbocharging, intercooling and other features that enhance efficiency. Further improvements can be achieved through other technologies such as low-viscosity oils and the use of precision cooling, whereby the engine coolant is applied only to those parts of the engine that become especially hot.

Another option available to PSV operators is to purchase vehicles with large engines, for the sake of long service life, and then to 'derate and despeed' the engine in order to save fuel. Up to five per cent savings in fuel consumption may be made using this technique (Department of Energy, 1989).

3.3.5. Transmission

There is potential for saving fuel through the optimisation of engine speeds using improved transmission systems. In cruising conditions, the availability of a suitable gear ratio to minimise engine speed can improve fuel economy by up to 20 per cent. To the same end, continuously-variable transmissions (CVTs) can be fitted to urban buses, with estimated fuel savings of 10 per cent (Department of Energy, 1989).

3.3.6. Emission controls

Approximately three quarters of buses and coaches are diesel-powered. Future emissions legislation is likely to require buses and coaches to be fitted with soot traps, with which a small reduction in fuel economy is associated (Department of Energy, 1989). However, buses and coaches are a major source of particulate pollution in urban areas, and the loss of fuel economy is likely to be less significant than the improvement in air quality.

3.3.7. Vehicle weight

The weight of PSVs, measured per passenger seat, has generally increased in recent years. There are several reasons for this: according to the Department of Energy (1989), the trend towards one-person operation in bus services has necessitated more powerful engines and

additional automatic door equipment. Long-distance services have also seen a widening of seats, and a general increase in the amount of equipment such as toilets, drinks dispensers and entertainment systems.

Vehicle weight could be reduced, and structural strength improved, by a switch to integral construction of the vehicle's body and chassis. The Department of Energy estimates that in urban conditions a 10 per cent reduction in vehicle weight would correspond to a five per cent improvement in fuel economy.

3.3.8. Kinetic energy storage systems

A substantial opportunity for fuel saving is offered by systems that accumulate the kinetic energy of a vehicle during braking, store it whilst stationary, and then use the stored energy to accelerate the bus again. Experimental designs have included flywheels and compressed air systems.

Flywheel systems comprise a rapidly-spinning wheel which is connected to the vehicle transmission by means of a clutch. The wheel spins whilst the bus is stationary, and its energy is used to get the bus moving again.

In an alternative arrangement, the same function is performed by a large container filled with compressed air: the kinetic energy of the bus is used to compress the gas, and the system is operated in reverse to accelerate the bus. A test vehicle fitted with such a device, named 'Cumulo', was developed in the 1980s, but never used in commercial operations.

The benefits of kinetic energy storage are dependent on the operating conditions: maximum savings occur in trips with frequent, short-duration stops. White (1986) estimates that fuel consumption could be reduced by up to 25 per cent using this method.

OPERATIONAL EFFECTS

3.3.9. Driving style

The management of bus operations can influence the fuel consumption of vehicles. The Department of Energy (1989) holds the view that 'driver education and increased awareness of techniques to improve fuel consumption appear to be the principal low-cost management activity'. Aspects of economical practices to be encouraged among drivers include the avoidance of severe acceleration and braking, the moderation of speed, and switching off the engine whilst stationary.

For coaches used in motorway operations, the use of speed-limiting devices can save fuel. By law, all new coaches registered in Britain must be fitted with a device that limits their speed to 70 mph or less. In practice, these devices are in many cases inoperative, as a result of either malfunction or deliberate damage. Government figures suggest that a large number of coaches are capable of travelling at speeds significantly higher than 70 mph (see Appendix 4), and the negative effect on fuel consumption is considerable.

3.3.10. Traffic management

The pattern in which a PSV is operated can influence fuel consumption. Urban road congestion results in poor fuel economy for buses, and a variety of measures are available for improving matters, including bus-only lanes and other 'bus priority' measures. A traffic signal control system called SCOOT has been developed that can respond to varying traffic flows by altering the 'green time' of the signals (see 3.2.16). SCOOT has been installed at junctions in many of Britain's towns and cities. An advanced version of SCOOT can respond to an approaching bus by turning green, thereby minimising delays for public transport.

Used in conjunction with other bus priority measures, this technology can reduce fuel consumption by up to 10 per cent, both by improving the fuel economy of the bus and by cutting the duration of its journey. In addition, reducing the number of stops can improve the fuel economy of a PSV; but this can become self-defeating if it reduces bus patronage.

3.4. Fuel economy in rail vehicles

3.4.1. Aspects of energy demand

Energy consumption in rail vehicles is dominated by two factors: firstly the mass of the train, which determines the energy required to accelerate it to its running speed, and secondly the aerodynamic resistance encountered during operation. The type of stock and the operating conditions will determine which of these is the more important. Typically, mass is more critical in low-speed journeys with short station spacings; whilst aerodynamic drag is important in high-speed or underground operations.

A further energy demand comes from the heating and air-conditioning of passenger compartments. Averaged over all seasons, between 11 and 15 per cent of energy consumption is for this purpose. Table 3.5 lists the primary energy consumption of different forms of rail operation, according to a study by the Department of Energy.

Table 3.5 Primary energy consumption of rail stock in Britain

Type	Energy consumption (GJ/100 train km)
<u>Diesel-powered:</u>	
High Speed Train	19.7
Main line locomotive	18.6
Diesel multiple unit	2.5
<u>Electrically-powered:</u>	
Main line locomotive	23.9
Electric multiple unit	2.9
Underground train	9.7 - 12.2
Light rail	2.4 - 4.8
Urban electric train	12.5

Source: Department of Energy, 1989.

3.4.2. Engineering effects and operational effects

The same approach is adopted here as in previous sections. Factors influencing fuel consumption may be divided into *engineering effects* and *operational effects*. Engineering effects are technical aspects of both the rail stock and the track upon which they operate. Operational effects, as before, are factors associated with the way in which the vehicles and system are run.

ENGINEERING EFFECTS

3.4.3. Vehicle weight

The weight of rail stock directly affects the energy needed to accelerate it to running speed, as well as, to a lesser extent, the rolling resistance. Rapid acceleration allows longer periods of 'coasting', in which the tractive power is not needed. British Rail estimates that in urban services a nine per cent reduction in vehicle weight offers an eight per cent energy saving (Department of Energy, 1989).

A major component of a passenger train's weight is the bogies. By building longer coaches, or allowing adjacent coaches to share a common bogie, the number of bogies per train can be reduced. The length of InterCity coaches has increased from 21m in the 'Mk 2' stock of the

1960s to 23m in the Mk 3 and Mk 4 coaches of the 1970s and 1980s. The Mk 5 stock for future trains is planned to use 26m coaches, representing the maximum length that can be accommodated by the British loading gauge.

Bogies themselves can be redesigned in lightweight form, with weight savings of over 50 per cent (ibid). The use of lightweight materials such as aluminium, alloys and composites, offers weight reductions in passenger coaches, as do new construction techniques such as the fitting of body panels using adhesives rather than bolts and rivets.

3.4.4. Engine design

New forms of diesel engine with greater efficiency offer fuel savings of around five per cent. The need for increased noise reduction may, however, impose a penalty of one per cent on fuel economy.

3.4.5. Transmission design

In many applications there is an energy-saving potential associated with increased acceleration, made possible by higher gear ratios. This is because rapid acceleration allows longer periods of coasting. For example, an electric multiple unit can reduce its energy consumption by 17 per cent and its maximum speed by one third, with no reduction in journey time, if the gear ratio is increased from 1 : 3.3 to 1 : 5.0.

The use of microprocessors to optimise gearchanges, engine power, coasting and braking can return energy savings of up to 30 per cent compared with conventional manually-operated systems.

3.4.6. Regenerative braking

In conventional braking systems, brake pads are used to convert the train's kinetic energy into heat, which is lost to the air. Alternatively, the motors may be used in reverse to generate electric current, which creates heat in banks of resistors. However, much of this waste can be avoided by converting the train's energy into electrical energy, which is fed back into the distribution network. This may be done by reversing the operation of the electric motors, and using them as generators driven by the train wheels.

Overall savings of around 15 per cent are possible using regenerative braking, and the benefits may be enhanced by the use of microprocessors to control the motion and energy demand of the train. The new Networker trains, recently introduced to Network South East,

make use of regenerative braking. Using this and other other energy-saving technology,¹ these trains use 24 per cent less electricity than their predecessors - despite increased speed and acceleration (Heaps, 1991).

3.4.7. Aerodynamic drag

Section 3.2.16 has shown that aerodynamic drag is a function of frontal area and drag coefficient, C_d . At full speed, a typical passenger train consumes approximately three quarters of its energy in overcoming drag. The aerodynamic design of passenger trains is therefore crucially important in determining energy consumption.

The principal contributors to aerodynamic drag are the bogies (40 per cent) and the surfaces of the rolling stock (40 per cent), with the shape of the nose contributing only around five per cent to overall resistance. In tunnels, aerodynamic drag increases by between 100 and 200 per cent, and the fraction of energy consumed in overcoming air resistance rises to 90 per cent (Gawthorpe, 1983)

In the last 15 to 20 years the aerodynamic design of passenger trains has improved by around 40 per cent. Much of this has been the result of better fairings, smaller gaps between cars and the elimination of opening windows and roof-mounted ventilators from many trains. However, the latter are associated with the introduction of air conditioning, which imposes an additional energy demand on the system.

Most of the potential for further improvements lies in locating extraneous equipment beneath the floor of the coach and surrounding it with fairings. Similar practices can be applied to the bogies, although this makes access for maintenance more difficult. Similarly, the pantograph (the arrangement that picks up power from overhead cables) can be modified to reduce its drag coefficient.

Modern express trains have a drag force typically 20 per cent less than that of 1960s and 1970s stock. Further reductions of 10 to 15 per cent are possible without radical design changes. In services where operating speeds are lower, such those on local lines, drag reductions of up to 40 per cent are possible in individual trains. Because of the low speeds, the benefit is translated into a modest five per cent reduction in energy consumption overall (ibid).

¹ Energy-saving innovations include a lightweight design, using aluminium bodies, and three-phase motors.

3.4.8. Electrification

A growing proportion of British Rail's track kilometres is electrified. The benefits of electrification are as follows:

- ❑ Electric traction is cheaper than diesel: Hamer (1979) estimates that when capital investment and maintenance costs are taken into account, electric is some 30 per cent cheaper. This is partially due to lower energy costs. In terms of delivered energy, electric trains are more efficient than diesel (although when the losses associated with the generation and distribution of electricity are considered, there is little difference between the two forms of traction).
- ❑ Electric engines are more reliable than diesel locomotives, as a result of their mechanical simplicity. This means that fewer trains are out of service at any time, and maintenance costs are between 50 and 65 per cent less than those of diesel stock (Department of Energy, 1989).
- ❑ Electric trains have better performance characteristics than diesel. An electric engine has a power-to-weight ratio some 50 per cent greater than an equivalent diesel. It can also 'withstand greater output for short periods, considerably in excess of its continuous rating, giving high rates of acceleration, or the ability to sustain speeds on gradients' (ibid). Reduced journey times tend to be associated with increased patronage (Hamer, 1979).

Recent electrification projects, and in particular the East Coast Main Line, have been justified on economic grounds. Routes with little traffic cannot make such justifications, and British Rail envisages no more than 52 per cent of its present route miles being eventually electrified. Potter (1990) holds the view that 'improvement in the cost-effectiveness of electrification and the need to replace a large quantity of old modernisation diesels tipped the balance in favour of electrification for many stock/line modernisation projects in the 1980s.'

Potter (op. cit.) summarises the situation as follows:

Electrification on British Rail is undertaken within the broadly commercial remit of the business sectors. Recent projects have majored on the cost-cutting potential of electrification and (to a lesser extent) its proven traffic-generating potential. However, with replacement of 1950s modernisation diesels approaching completion, further major electrification appears unlikely.

In terms of primary energy demand, and emissions of CO₂, there is little or no advantage in electrification as compared with diesel traction. However, if electricity generation and distribution were to become more efficient, as seems likely, or switch to renewable sources

of energy, electric traction would develop a significant advantage over diesel in terms of both energy efficiency and greenhouse forcing. In addition, the 'traffic generation' effects should not be overlooked: if electrification has the effect of attracting travellers to rail rather than less efficient modes such as car or air, there would be an overall reduction in CO₂ emissions.

3.4.9. Track layout

Energy savings are associated with the elimination of gradients and curves from rail lines, leading to reduced braking and acceleration. However, realigning routes is an expensive operation, and possible only in a small number of cases (Department of Energy, 1989). More important is the easing of very low speed limits (for example 60 km/h curves or crossings) on high-speed (200 km/h) lines, and other local measures. Such work is often undertaken as part of wider engineering projects, such as electrification and resignalling.

OPERATIONAL EFFECTS

3.4.10. Track maintenance

Considerable energy losses are incurred when rail traffic is required to slow or stop whilst travelling along track that is being repaired. Savings in both time and energy could be made if the maintenance work were modified so that speed restrictions were fewer and lesser.

An example of this can be found in the new Dynamic Track Stabilisers, which allow new track to be used immediately rather than after a 'bedding in' period (British Rail, 1991). Previously speed limits as low as 30 km/h were imposed for up to two weeks after the new track was laid.

3.5. Fuel economy in aircraft

In the preceding chapter it was shown that the SEC of air travel has improved significantly since the 1960s. This improvement has been characterised by a trend towards larger aircraft, which have the dual advantage of both providing greater energy efficiency and accommodating a larger number of passengers.

3.5.1. The influence of trip length on aircraft fuel economy

Long flights are generally more fuel-efficient than short ones, partly because short flights tend to be made by smaller, less fuel-efficient aircraft. But there is a more fundamental basis for the difference. The 'cruise' phase of a flight is generally the most economical in terms of fuel use, whilst climbing consumes a large amount of energy.¹ In short flights, such as those between UK destinations, ascent and descent account for a large proportion of the journey.

Thus for any type of aircraft, fuel economy improves as the length of flight increases. The variation tends to level off at distances greater than 1,000 km, as the ascent phase diminishes in significance and the overall fuel consumption approximates to the fuel consumption associated with the cruise phase alone.

3.5.2. Aircraft effects and operational effects

Given the pattern of flights provided by domestic air services in the UK, there are a number of influences on aircraft fuel consumption which may be categorised into *aircraft effects* and *operational effects*.

AIRCRAFT EFFECTS

3.5.3. Aerodynamics

The Department of Energy (1989) has described in detail the aspects of aircraft design that can contribute to improved fuel consumption characteristics. Progress in computer design has allowed better flow modelling to be performed, and there has also been some experimentation with laminar flows and grooved skins. The potential of the latter to improve fuel consumption has been estimated to be 12 to 25 per cent and 20 per cent respectively.

3.5.4. Materials

Aluminium alloys are the principal material in the structure of aircraft, and are likely to remain so. However, alloys with superior physical properties are being developed, either through enhanced purity or in the form of new combinations of metals. In addition,

¹ In a typical 900 km flight, the initial ascent consumes as much fuel as the entire cruise phase (Department of Energy, 1989).

composite materials such as glass fibre, Kevlar and carbon fibre are likely to become more common in airframe components.

3.5.5. Engines

Most medium and large aircraft are powered by turbofan engines, whilst smaller aircraft, used in shorter trips, tend to have turboprop engines. Both fuel consumption and maximum thrust have increased significantly since the early days of passenger jets. Improvements in efficiency may be divided into three categories:

- ❑ propulsive efficiency, or the ratio of work done by the engine to the energy increase of the jet as it passes through the engine;
- ❑ thermal efficiency of the Brayton combustion cycle, or the efficiency with which fuel is converted to mechanical energy;
- ❑ component efficiency, particularly with regard to compressors, turbines and burners.

The Department of Energy (1989) estimates that historical increases in efficiency have been divided approximately equally between these three categories.

3.5.6. Avionics

In recent years, computers have been used increasingly to control aircraft. For example, the A320 Airbus is the first commercial aircraft to be equipped with 'fly by wire' controls, whereby computers provide an interface between the pilot and the control surfaces. The introduction of computerised controls offers significant reductions in weight and fuel consumption (ibid).

OPERATIONAL EFFECTS

3.5.7. Flight management

Finally, computerised systems may be used to devise flight patterns in such a way that fuel consumption can be minimised. Technologies such as satellite navigation, microwave landing systems and advanced weather forecasting can all reduce the amount of excess fuel consumed by aircraft during a typical flight.

3.6. Summary

Vehicle fuel consumption has a direct effect on emissions of CO₂, along with occupancy. This chapter has described the many factors that influence the fuel consumption of different modes. These may be broadly divided into design (or vehicle) effects, and operational effects.

In general, vehicles return a considerably lower level of fuel economy than the maximum that is technologically possible. This is particularly noticeable in private cars and, to a lesser extent, in aircraft. In part this is because it takes time for new, more efficient designs to find their way into the national vehicle stock. But a more important reason is that other characteristics, such as comfort and performance, are traded off against fuel economy. The point at which the trade-off occurs is determined crucially by the price of fuel. Experience from other European countries suggests that long-term fuel price has a positive influence on the average fuel economy of the national car stock.

Operational effects, too, can have a considerable influence on fuel consumption. In the case of cars, this includes driver behaviour and measures to reduce the incidence of uneconomical driving conditions such as congestion and cold running. In other modes, particularly rail and air, new operating systems may be used to ensure that vehicles are operated in the most economical way possible. The proportion of operating costs that is spent on fuel is relatively large compared with the same figure for cars, and there are significant financial gains to be made from improving fuel economy.

There is a conspicuous gap between real-life fuel consumption values and what is technologically possible. This illustrates the complexity of the situation, and the effect of other considerations that are traded off against fuel economy. On the one hand, the existence of such a gap represents the institutional barrier that stands in the way of large-scale improvements in fuel economy. On the other hand, it indicates a huge and largely untapped resource of energy efficiency which may be tapped as part of a strategy to curb emissions of CO₂.

Chapter Four

‘BUSINESS AS USUAL’ CARBON DIOXIDE EMISSIONS FROM PERSONAL TRAVEL

4. 'BUSINESS AS USUAL' CARBON DIOXIDE EMISSIONS FROM PERSONAL TRAVEL

“Transport, and road transport in particular, will present insoluble problems in terms of pollution, energy consumption and congestion unless there are policy changes.”

- The European Parliament, 13 December 1990

4.1. The need for a model

In the preceding chapters, the contribution of personal travel to greenhouse emissions has been described in detail. In order to ascertain how this contribution will develop in the future, it is necessary to construct a model of the passenger transport sector.

Chapter 2 showed that there are a number of different greenhouse gases arising from transport activities, each with a different lifetime. However, only CO₂ will be considered henceforth, because

- ❑ To model each of these gases individually would greatly complicate matters, and is beyond the capacity of this study;
- ❑ So far the various national targets for reducing greenhouse emissions have considered CO₂ only, and this study aims to evaluate transport's role in achieving these targets.

The model should have as its inputs various aspects of personal travel demand, and its output should take the form of an annual quantity of carbon dioxide resulting from travel activities.

4.2. The scenario approach: SPACE

The use of *scenarios* is a common method of examining the future effects of various policies. By constructing them it is possible to circumvent the difficulty of making accurate forecasts. Instead, a number of possible futures can be formulated and their consequences examined. No attempt is made to establish which scenario is the 'most likely'.

The initial requirement of this study is to determine future levels of travel-related emissions, assuming no change in present policies. Such a future, characterised by the absence of a dedicated response to the global warming threat, may be termed 'business as usual'. This is defined as the progression of events that will take place as a continuation of present policies and trends. It is assumed that no policy changes will take place other than those currently under development. For example, energy efficiency might be expected to improve as a result of market mechanisms, but no more.

In this study, passenger transport in Britain is described using a computer model developed by the author called *SPACE: Scenario Projections of Aggregate Carbon Emissions*. Having been developed and calibrated using historical data, the SPACE model is used to examine the effects of a 'business as usual' scenario.

4.2.1. Structure of the SPACE model

The SPACE model is based on Microsoft Excel spreadsheet software. For each travel mode a single spreadsheet tabulates travel demand (journey lengths and journey frequencies) from different user categories, and adds all the components together to give a single figure for passenger mileage (and vehicle mileage, where applicable), in a time-series layout. Each column corresponds to one year, covering 1978, 1985, 1988, 1990, and thenceforth to 2025 in five-year intervals.

A summary spreadsheet then draws together the aggregate figures from each of the subsidiary spreadsheets, and combines them with data relating to energy consumption and fuel characteristics to produce a total figure for annual CO₂ emissions.

The model thus comprises two parts:

- (a) Individual spreadsheets giving transport demand in each mode, in terms of journey lengths and frequencies, according to journey purpose, type of area, and car ownership; aggregated to give a figure for total annual mileage;
- (b) A summary spreadsheet containing the mileage figures from (a) together with details of fuel economy, fuel type, loading factors and so on to provide a figure for overall CO₂ emissions from each mode.

Figure 4.1 is a typical spreadsheet from SPACE, showing the disaggregation of travel demand for a particular mode. The elements contained in SPACE are described in the following sections.

Figure 4.1 Sample spreadsheet (blank) from SPACE

	A	B	C	D	E	F	G	H	I	J	K	L
1		1978	1985	1988	1990	1995	2000	2005	2010	2015	2020	2025
2	MODE = ?											
3	GB POPULATION	54621000	55061000	55317000	55846000	56665000	57275000	57552000	57698000	57889000	58135000	58259000
4	GB POPULATION FRACTIONS:-											
5	Rural with cars											
6	Rural without cars											
7	Intermediate with cars											
8	Intermediate without cars											
9	Urban with cars											
10	Urban without cars											
11												
12	GB POPULATION SPLIT:-											
13	Rural with cars pop											
14	Rural without cars pop											
15	Intermediate with cars pop											
16	Intermediate without cars pop											
17	Urban with cars pop											
18	Urban without cars pop											
19												
20	JOURNEYS PER CAPITA DATA:-											
21	R with cars work trips											
22	R with cars shopping or pers											
23	R with cars social or ents											
24	R with cars holiday or other											
25	R without cars work trips											
26	R without cars shopping or pers											
27	R without cars social or ents											
28	R without cars holidays or other											
29	I with cars work trips											
30	I with cars shopping or pers											
31	I with cars social or ents											
32	I with cars holiday or other											
33	I without cars work trips											
34	I without cars shopping or pers											
35	I without cars social or ents											
36	I without cars holiday or other											
37	U with cars work trips											
38	U with cars shopping or pers											
39	U with cars social or ents											
40	U with cars holiday or other											
41	U without cars work trips											
42	U without cars shopping or pers											
43	U without cars social or ents											
44	U without cars holiday or other											
45	AVERAGE TRIP LENGTHS (MILES)-											
46	R with cars work trips TL											
47	R with cars shopping or pers TL											
48	R with cars social or ents TL											
49	R with cars holiday or other TL											
50	R without cars work trips TL											
51	R without cars shopping or pers TL											
52	R without cars social or ents TL											
53	R without cars holidays or other TL											
54	I with cars work trips TL											
55	I with cars shopping or pers TL											
56	I with cars social or ents TL											
57	I with cars holiday or other TL											
58	I without cars work trips TL											
59	I without cars shopping or pers TL											
60	I without cars social or ents TL											
61	I without cars holiday or other TL											
62	U with cars work trips TL											
63	U with cars shopping or pers TL											
64	U with cars social or ents TL											
65	U with cars holiday or other TL											
66	U without cars work trips TL											
67	U without cars shopping or pers TL											
68	U without cars social or ents TL											
69	U without cars holiday or other TL											
70												
71	Work trips miles total											
72	Shopping or pers miles total											
73	Social or ents miles total											
74	Holiday or other miles total											
75												
76	Rural miles total											
77	Intermediate miles total											
78	Urban miles total											
79												
80	TOTAL MILEAGE											

4.2.2. Use of historical data in constructing scenarios

The SPACE model disaggregates in some detail the demand for travel, and evaluates the subsequent emissions of CO₂. The factors used in creating these subdivisions are

- household car ownership;
- journey purpose;
- journey length;
- journey frequency;
- choice of mode;
- type of area in which traveller resides (urban, intermediate or rural).

The National Travel Survey (NTS), carried out periodically by the Office of Population Censuses and Surveys, is used to obtain this information. Special cross-tabulations of the 1979 and 1985 surveys were specified and ordered from the NTS, to provide an historical reference upon which to base future projections. These data take the form of

- (a) average journey lengths (in miles), and
- (b) average journey frequencies (in yr⁻¹)

in each of the following population subgroups:

- RURAL WITH CARS
- RURAL WITHOUT CARS
- INTERMEDIATE WITH CARS
- INTERMEDIATE WITHOUT CARS
- URBAN WITH CARS
- URBAN WITHOUT CARS

'WITH CARS' defines people living in households with one or more vehicle;

'WITHOUT CARS' defines those in households that own no vehicle.

'RURAL' refers to households in settlements of fewer than 3,000 inhabitants;

'INTERMEDIATE' refers to those in settlements between 3,000 and 100,000 inhabitants;

'URBAN' refers to households within settlements with more than 100,000 inhabitants.

Within these user categories, the journeys undertaken are subdivided according to *purpose* as follows:

- WORK
- SHOPPING AND PERSONAL
- SOCIAL AND ENTERTAINMENTS
- HOLIDAY AND OTHER

This analysis was performed for five modes of travel, namely car, rail (including London Underground), bus, walk and cycle. For other modes, this detailed decomposition was not performed. Either the specific data were not available from the NTS tables, as in the case of air and light rail travel, or the category was too small to justify full analysis, as in the case of motorcycles.

4.2.3. Calibrating traffic demand for the base year

The base year for all projections is 1988. The data for each journey category are extrapolated to 1988 from the 1978/9 and 1985/6 NTSs and normalised to fit the aggregate 1988 figures from Transport Statistics Great Britain (Department of Transport, 1991a).

The match between the aggregated 'bottom up' figures of the NTS and the 'top down' data of the Department of Transport was generally very good, with only minor calibration required.

4.3. Establishing a baseline: 'Business as Usual'

The first scenario constructed with the SPACE model represents 'business as usual'. This is designed to establish the future level of CO₂ emissions from personal travel assuming a continuation of present policies. The baseline scenario is modelled on known government policies and forecasts, and aims to evaluate the effect of these on future CO₂ emissions.

The SPACE model having been calibrated to fit aggregate 1988 data, Scenario 1 was constructed up to the year 2025. Contained in the following sections is a complete description of the assumptions underlying the inputs of 'Business as Usual'.

4.4. Population and car ownership

Population is a key determinant of passenger transport demand. The SPACE model examines not only the total number of transport users, but also

- the proportion living in car-owning households, and
- the proportions living in rural, intermediate and urban areas.

The total population for Britain is expected to grow by a little more than 0.1 per cent per annum. Population forecasts were taken from the 1989 Road Traffic Forecasts (Department of Transport, 1989a) and are reproduced in Table 4.1.

Table 4.1 Government forecast of Great Britain's population up to 2025 (million)

1991	55.846
1996	56.665
2001	57.275
2006	57.552
2011	57.698
2016	57.889
2021	58.135
2025	58.259

Source: Department of Transport, 1989a

The basis of the Government's forecasts for car traffic is a vigorous growth in car ownership. The Department of Transport (1989a) notes that car ownership in Britain was 310 cars per 1000 population in 1986, compared with 1985 figures of 379 for France, 428 for West Germany and 552 for the United States.

The Department acknowledges that there is likely to be a 'saturation' level for car ownership when 90 per cent of the population of driving age own a car. Given that a fairly constant 71 to 73 per cent of the population will be of driving age up to the year 2025, this equates to a level of approximately 650 cars per 1000 people (cpt). On this basis they forecast that car ownership will rise to a level between 523 and 582 cars per 1000 population by the year 2025. If car ownership were to exceed 650 cpt as a result of people possessing more than one car each, there would be no effect on traffic levels since only one car can be driven at any time.

It was assumed for Scenario 1 that, in all three types of geographical area, the proportion of people living in households with one or more cars would rise considerably. Table 4.2 gives details of the assumptions that were made.

Table 4.2 Distribution of population according to household car ownership in Scenario 1.

	% of people in car-owning households	
	1988	2025
Rural areas	87.2	95.0
Intermediate areas	78.3	90.0
Urban areas	69.7	85.0

(‘Car-owning’ is defined by households with one or more cars.)

To estimate the *geographical* distribution of population, it is necessary to examine past trends. An analysis by Champion (1987a) shows that for many years Britain’s main cities were losing people at a significant rate, of around 10 - 20 people per 1000 population per year. Other metropolitan areas, as well as smaller cities, had a lower effluence rate (3 - 8 persons per 1000 per year). Meanwhile industrial areas, new towns, resorts and other areas were growing at a rate of 5 - 10 persons per 1000 population per year.

However, this trend has tended to level off since the mid-seventies, with rates of growth or decline becoming more modest. In 1981-84, the annual loss of population from cities had fallen to 5 per 1000, whilst the influx of people into areas of expansion was at the same level.

Later figures (Champion, 1987b) show that the outflow of population from Greater London is slowing even more, and in 1984-85, for the first time since before the First World War, the population of the capital was expanding.

Champion (1990) holds the view that the change in population distribution observed in the period 1985-89 (OPCS, 1990) is likely to continue for some time. The main growth will continue to be in rural and intermediate areas, with less change in urban population. For Scenario 1 this trend has been adopted, and the details are summarised in Table 4.3.

Table 4.3 Population trends projected in Scenario 1

	Change in population (% per annum)
Urban areas	- 0.08
Intermediate areas	+ 0.58
Rural areas	+ 1.10

Source: OPCS, 1990.

4.5. Transport demand

4.5.1. The 1989 National Road Traffic Forecasts

The National Road Traffic Forecasts (NRTF) (Department of Transport, 1989a) contain revised predictions of road traffic up to the year 2025. The forecasts are considerably higher than the previous estimates made in 1984. Road traffic volume is predicted to grow in a linear fashion, reaching between 183 and 242 per cent of its 1988 value by the year 2025. The main determinant of traffic volume is considered to be economic growth, with fuel price exerting a lesser influence. Gross domestic product (GDP) is expected to reach between 202 and 315 per cent of its 1988 level by 2025. The upper and lower limits of the forecast are based on different assumptions about GDP and fuel price.

Table 4.4 summarises the 1989 NRTF. All categories of road traffic other than buses and coaches are predicted to grow considerably.

Concern has been expressed that the growth rates implicit in the 1989 NRTF are unrealistically high. The consequences for greenhouse emissions are one cause of this concern, whilst some have pointed to the social and land-use implications of such a large-scale expansion in road traffic; see for example Adams (1990) and the Royal Town Planning Institute (1991).

The rapid rate of traffic growth projected by the 1989 NRTF has prompted criticism of the forecasting techniques employed by the DTp. The most common objection is that economic growth is regarded as the prime determinant of traffic growth, via its influence on car ownership. The 1989 forecasts brought into relief the need for 'saturation' effects to be taken into account, whereby physical limits are placed on the amount of traffic that can exist. The Royal Town Planning Institute (op. cit.) has expressed the view that the historical growth in road traffic has largely been absorbed by existing road capacity, which is now unable to cope with further increases in vehicle numbers:

... it may no longer be reasonable to assume that the physical fabric, or the pattern of uses and trips within the fabric, can continue to absorb change. If traffic increases over recent decades have been largely absorbed within the existing fabric, and that capacity largely used up in many areas, further growth in traffic demand may create accelerating pressures for change in urban form, even when the actual growth in demand may be decelerating.

These concerns are related to the observation that most of the Government's roadbuilding programme consists of trunk roads beyond the limits of urban areas, and will encourage greater numbers of vehicles to enter already-congested towns and cities.

It is possible that the DTp will revise its 1989 forecasts of road traffic to take better account of demand constraints such as fuel price, environmental implications and congestion. The MVA Consultancy is to undertake this review (Local Transport Today, 1991). However, the results of the revision were not available at the time of writing, and Scenario 1 therefore makes use of the 1989 forecasts.

Table 4.4 Summary of the 1989 Road Traffic Forecasts

	Growth in vehicle kilometres, 1988 - 2025 (%)	
	Low	High
Cars	82	134
Light goods vehicles	101	215
Heavy goods vehicles	67	141
Buses and coaches	0	0
All traffic	83	142

Source: Department of Transport, 1989a.

4.5.2. Car traffic projections

The 1989 NRTF assumes an annual growth of between 2.2 and 3.6 per cent in car traffic. The DTp's quarterly traffic data reveal that in 1989 the actual growth was almost twice the 'upper' value, at 7.1 per cent. The growth in 1990 and 1991 was more modest. Whilst it is by no means clear what rate of annual growth is sustainable for the period to 2025, it would appear that the upper forecast will be a more likely outcome than the lower.

The car sector model was therefore constructed in such a way as to produce an aggregate traffic volume marginally less than the 'high' forecast of the 1989 NRTF. Trip lengths and

journey frequencies were projected linearly in such a way that the total car mileage was equal to this volume of traffic.

Converting passenger kilometres to car kilometres requires assumptions to be made concerning vehicle occupancy. Chapter Two showed that car occupancy has historically declined as the number of cars in use has increased. This trend is projected forward in Scenario 1 in a linear fashion, with car occupancy declining in all areas by 0.1 per cent per annum. Table 4.5 gives the assumptions made about car loading up to the year 2025. Car occupancies remain higher in urban areas, in accordance with evidence from the National Travel Surveys of 1978 and 1985.

Table 4.5 Assumed car occupancies for Scenario 1 up to 2025 (persons per car)

Type of household	1978	1985	1988	2025
Rural	1.79	1.61	1.53	1.47
Intermediate	1.86	1.70	1.63	1.57
Urban	1.89	1.67	1.65	1.58

4.5.3. Bus and coach traffic projections

The 1989 NRTF predicts a zero growth in bus and coach traffic up to the year 2025. This does not, however, imply a zero growth in passenger kilometres. The trend towards smaller vehicles that has taken place in recent years, particularly after the deregulation of bus services which began in 1986, has meant that more vehicles are required to carry the same number of passengers. Table 4.6 gives details of this trend, extrapolated to 2025.

Furthermore, the population of Great Britain is expected to be some five per cent greater in 2025 than it is at present (see Table 4.1 above). The 'zero growth' prediction of the 1989 NRTF therefore implies that bus travel *per person* will decline. The reduction in average occupancy observed in Table 4.6 reflects this diminishing patronage, as well as a continuation of the trend towards smaller vehicles.

Table 4.6 Bus and coach travel forecasts in Scenario 1

	1988	1990	1995	2000	2005	2010	2015	2020	2025
Average occupancy	9.5	8.7	8.6	8.4	8.3	8.2	8.1	8.0	8.0
Passenger km (billion)	39.6	39.7	37.0	36.4	36.0	35.6	35.1	34.8	34.6
Vehicle km (billion)	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3

The Royal Town Planning Institute (1991) suggests that greater attention should have been given to bus demand in the compilation of the NRTF:

Comparatively little attention is paid to [buses and coaches] in NRTF, which assumes that total kilometres by bus and coach will be constant at the 1988 level over the forecast period, for both the high and low economic growth projections. While this may be a reasonable approach ... it encourages potential inter-modal effects to be disregarded. Significant transfers from car to bus might only be achieved by policy, but the land use dispersal associated with increased car use would be likely to be lengthening bus trips, or causing former walk trips to become bus trips.

In accordance with the NRTF, the bus and coach sector of Scenario 1 is constructed to give nil growth in vehicle kilometres over the period 1988 to 2025, whilst accounting for changes in occupancy and population. As in the car sector, the individual categories are extrapolated linearly forward in time so as to match the NRTF aggregate figures.

Table 4.6 also shows the trends in vehicle and passenger kilometres for buses in the period to 2025, as projected in Scenario 1. The decline in passenger kilometres is slower than that observed historically, but is constrained by the 'nil growth' projections for vehicle kilometres published in the 1989 NRTF. The decline in patronage that has occurred since deregulation in 1986 is particularly sharp, and it is to be expected that it will bottom out to a level of demand representing a 'core market' of bus users. Such a trend, detailed in Table 4.6, is assumed in Scenario 1. The table also shows how the average occupancy of buses is expected to change over the same period, based on a continuing movement towards smaller vehicles and lower load factors.

4.5.4. Rail traffic projections

British Rail does not make long-term forecasts of rail traffic, but instead restricts its projections to five years ahead. The latest estimates for the passenger sector are given in Table 4.7.

Year	1985/86	1990/91 (actual)	1994/95
Passenger km	100	112 (115)	126
Passenger train km	100	117 (113)	120

Source: British Rail, 1991.

The 'Business as Usual' scenario assumes a continuation of the 2.3 per cent annual growth rate in passenger mileage observed over the period 1978-88. Additionally, the contribution of urban rail is expected to make an increasingly significant contribution.

At the beginning of 1992, urban rail schemes were operating in London, Glasgow, Manchester, Newcastle and Blackpool, with a project under construction in Sheffield. Almost 40 other LRT proposals were under consideration. Some projects have been rejected for various reasons, including those in Leicester, Swansea and Aberdeen, and it seems likely that a significant number of those currently under review will suffer the same fate. Nevertheless, in view of the interest shown in light rail schemes, Scenario 1 assumes a 50 per cent increase in LRT passenger mileage by the year 2025.

Table 4.8 outlines the assumptions made concerning the future level of traffic in the passenger rail sector.

	1988	1990	1995	2000	2005	2010	2015	2020	2025
Passenger km (billion)	41.2	40.7	48.1	52.6	57.1	61.3	65.8	70.2	74.5
- of which BR (%)	91	83	84	84	84	86	86	86	86

In the decade from 1979 to 1989, the average number of passengers carried by British Rail per train has varied little. In 1981 it dropped to 92, whilst in 1988 it reached 101; see Table 4.9. Currently BR is trying to expand passenger capacity without extending the vehicle stock, and increased seating capacity is an active policy. However, it should be noted that expanding the seating capacity of carriages serves largely to provide seating for passengers who would previously have had to stand, rather than enabling additional passengers to use the train. For this reason the growth in average occupancy on BR trains is expected to be modest. Table 4.10 shows the projected increase for BR passenger trains up to the year 2025.

The opposite effect is expected to take place in other types of rail transit. Traditionally the London Underground railway has accounted for most of the non-BR rail mileage in Britain. Loading factors here show an increasing trend throughout the 1980s as the demand for travel rose. In 1987 the average number of people carried by a London Underground train was 129; see Table 4.9.

Table 4.9 Average rail occupancies, 1979-89 (persons per train)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
BR	93	92	95	95	96	95	99	99	101	97	96
LU	91	84	80	96	113	123	127	129	128	127	116

LU = London Underground.

Source: Department of Transport, 1991a.

However, other urban rail schemes, whether operational or under construction, will not achieve such high occupancies as those observed on the London Underground. The Tyne and Wear Metro, for example, has smaller trains than London Underground - 84 seats per train and an average occupancy of 30 (Withrington, 1990) - whilst the corresponding figures for Strathclyde's network are typically 90 and 34. As new LRT schemes become operational, the proportion of mileage travelled on the London Underground will therefore diminish, and the average occupancy for all urban rail travel will decrease.

Table 4.10 gives details of the occupancy for rail travel in Scenario 1, in which new LRT schemes are built with vehicle and loading characteristics technically similar to those of the networks operating in Strathclyde and Tyne and Wear.

Table 4.10 Average rail occupancies in Scenario 1 (persons per train)

	1988	1990	1995	2000	2005	2010	2015	2020	2025
Occupancy									
- BR	128	96	103	105	106	107	108	110	111
- Other rail	117	116	108	102	95	89	83	76	70

4.5.5. Air traffic projections

As explained in Chapter Two, this study concerns personal travel within the UK, and its appraisal of air traffic is restricted to domestic operations; that is, journeys between destinations within the UK.

The NTS does not include 'air' as a distinct category, and so a detailed breakdown of domestic air travel is not possible as it was for the other modes. Instead data have been obtained from the Department of Energy (1989), which has constructed scenarios of energy use in the air transport sector.

Generally, demand for air travel is expected to increase for domestic journeys. But growth in demand will be subject to constraints, particularly on runway availability and airport terminal capacity (ibid). One consequence of these limitations is likely to be an increase in the average seating capacity of aircraft, so that runways and airspace are used more economically. The implications of such a trend are included in the SPACE model.

The Department of Energy (1989) has taken account of these constraints and derived projections for air travel up to the year 2010. The first of their scenarios envisages a high rate of economic growth, a low rate of increase in fuel prices, and 'slow technical change'. Scenario 1 will assume this set of air traffic projections to represent 'business as usual'. For the years 2010 to 2025, the pre-2010 growth is extrapolated linearly. Table 4.11 summarises the demand for air travel in Scenario 1.

Table 4.11 Growth in domestic air traffic projected in Scenario 1

Year	1988	1990	1995	2000	2005	2010	2015	2020	2025
Domestic air traffic (billion passenger km)	4.67	5.16	6.44	7.69	8.95	10.22	11.47	12.74	14.00

As explained above, the increasing pressure on aircraft infrastructure is likely to produce an increase in the average seating capacity of aircraft. Load factors, however, will not necessarily be affected. The Department of Energy (1989) has investigated this area, and found that “domestic scheduled service load factors have fallen ... from 68 per cent [in 1963] to 61 per cent in 1986.”

Although load factors on international and non-scheduled services tend to be higher, it is not expected that those on domestic flights will rise appreciably in the future. The Civil Aviation Authority expects this figure to remain constant at around 60 per cent (Department of Energy, op. cit.). It is therefore assumed that aircraft load factors for domestic services will remain constant at 60 per cent up to the year 2025, regardless of changes in seating capacity.

4.5.6. Motorcycle traffic projections

Petroleum consumption and CO₂ emissions associated with motorcycles are comparatively small, and barely significant in an analysis of transport energy consumption. However, motorcycles have been included in the SPACE model, partly for the sake of completeness and also because motorcycles may in the future offer a fuel-efficient alternative for many car journeys.

Scenario 1 envisages a modest growth in motorcycle traffic, of 25 per cent by 2025. Table 4.12 gives details of this trend.

Year	1988	1990	1995	2000	2005	2010	2015	2020	2025
Motorcycle traffic (billion vehicle km)	6.11	6.19	6.40	6.61	6.82	7.02	7.22	7.43	7.64

4.5.7. Walking and cycling projections

Walking and cycling are covered in detail by the SPACE model, based on the National Travel Survey tabulations. No information is available on the likely long-term trend in cycle and walk mileage, and estimates are based on past trends. Scenario 1 involves a 30 per cent increase in cycle mileage between 1988 and 2025, reflecting the recent revival of interest in cycling as a travel mode. Walking is expected to decline by 25 per cent in the same period,

as journeys are transferred to cycling and motorised modes of travel. Table 4.13 gives details of these projections.

Year	1988	1990	1995	2000	2005	2010	2015	2020	2025
Cycle traffic (billion km)	3.89	3.96	4.11	4.28	4.40	4.54	4.70	4.87	5.04
Pedestrian traffic (billion km)	10.45	10.39	10.15	9.89	9.52	9.16	8.80	8.44	8.07

4.6. Energy consumption

Having established 'business as usual' projections of travel demand in each modal category, it is necessary to consider energy supply. In particular, assumptions must be made for each mode concerning:

- fuel economy, and
- the nature of fuels used.

The approach adopted here will consider *primary energy* consumption; that is, the total energy demand of a transport mode including the energy costs of producing, storing and delivering the fuel. The importance of using primary, rather than delivered, energy as a measure is explained in Chapter Two.

4.6.1. Car fuel economy

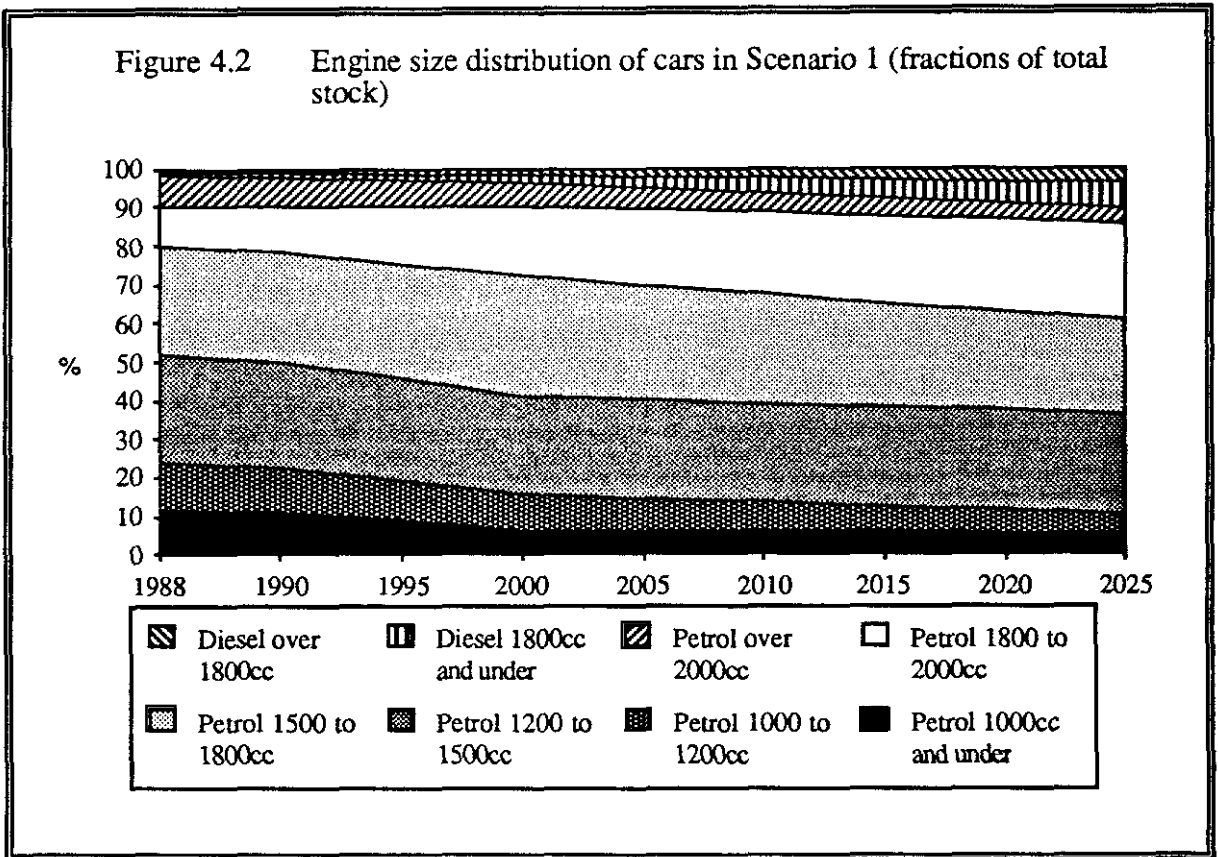
The fuel economy of road vehicles is a crucial determinant of overall energy consumption. Historically, car fuel economy has shown a slight improvement from year to year as automotive technology has enhanced the efficiency of new vehicles. However, fuel prices have generally not been sufficiently high to stimulate great interest in fuel economy, and the improvements in technology have been used primarily to increase the power of a given engine capacity. The effect whereby performance takes precedence over fuel economy in the deployment of new technology has been described in detail in Chapter Three.

In Scenario 1 it is assumed that market mechanisms, coupled with technological advances, will continue to yield slight improvements in average car fuel economy. Of equal importance is the distribution of the UK car fleet between different categories of *engine size*. As engine technology advances, a given power output can be attained by progressively smaller engines. This implies that the fraction of cars in the largest engine size category would decline in favour of smaller engine sizes.

However, in the absence of regulations or market mechanisms favouring fuel economy, there will be little incentive for consumers to purchase more economical vehicles. The proportion of cars in the smallest engine size category will not, therefore, grow to the extent that technological progress allows.

This effect is visible in the historical figures for car fuel consumption. Figure 3.2 has shown that car fuel economy improved only marginally in the period 1970 to 1987, because the new developments in vehicle efficiency were applied to the production of more powerful cars rather than more economical ones.

Figure 4.2 below gives the assumptions that are made regarding the engine size distribution of cars up to the year 2025.



Not only is the engine capacity distribution of the UK car stock relevant to overall fuel economy; attention must also be given to the average fuel economy of each engine size category. Historically, technical advances have produced a modest annual improvement in the fuel economy of a given engine size, as explained in Chapter Three.

Scenario 1 assumes a continuing but modest improvement in the specific fuel economy of all engine capacities. For petrol engines, fuel economy rises by 10 per cent between 1988 and 2010; the improvement in the period 2010 - 2025 is five per cent. For diesel engines the improvements are 17 per cent and 10 per cent respectively. Table 4.14 gives details of the trend in average fuel economy assumed in Scenario 1.

Table 4.14 Fuel economy values assumed in Scenario 1 (l/100km)

	1988	1990	1995	2000	2005	2010	2015	2020	2025
Petrol-engined									
Up to 1000 cc	7.60	7.54	7.38	7.22	7.07	6.91	6.85	6.72	6.58
1001 - 1200 cc	8.30	8.23	8.06	7.89	7.72	7.55	7.49	7.34	7.19
1201 - 1500 cc	8.90	8.83	8.64	8.46	8.27	8.09	8.03	7.87	7.70
1501 - 1800 cc	9.80	9.72	9.52	9.31	9.11	8.91	8.84	8.66	8.48
1801 - 2000 cc	10.60	10.51	10.29	10.08	9.86	9.64	9.56	9.37	9.18
Over 2000 cc	13.70	13.59	13.31	13.02	12.74	12.46	12.36	12.11	11.86
Diesel-engined									
Up to 1800 cc	6.40	6.31	6.10	5.89	5.68	5.47	5.36	5.17	4.97
Over 1800 cc	7.70	7.60	7.34	7.09	6.84	6.58	6.45	6.22	5.98

4.6.2. Bus and coach fuel economy

As described earlier, the late 1980s have seen a trend towards smaller buses in cities. Smaller vehicles typically consume less fuel than traditional single or double-decker buses, but their smaller seating capacity means that their fuel consumption *per seat kilometre* is higher than that of larger vehicles. Scenario 1 assumes a continuation of the trend towards smaller vehicles, and thus a progressive improvement in the average fuel economy of buses.

Coaches, on the other hand, show no changes in body size. Their fuel consumption is not expected to improve other than by a small amount resulting from technical refinements.

Table 4.15 gives the projected aggregate fuel economy of buses and coaches in Scenario 1. The improvement in fuel consumption is dramatic, reflecting a transition to smaller vehicles. As explained above, the reduced seating capacity will offset some of this gain.

Year	1988	1990	1995	2000	2005	2010	2015	2020	2025
Fuel economy (l/100km)	35	34	32	30	27	25	23	21	18

4.6.3. Rail fuel economy

Economic performance requirements for British Rail already require that fuel costs are kept as low as possible. Consequently the scope for fuel economy improvements in the rail sector is less than that for cars. Nevertheless, as new stock is introduced it is to be expected that fuel economy will improve, as a result of new technologies including regenerative braking, reduced vehicle weight and better aerodynamics.

Of greater significance is the degree of *electrification* in the rail sector. Currently just under 50 per cent of British Rail's train kilometres are covered by electric traction. The consequences of further route electrification for overall energy consumption are considerable. Since electric trains are powered by the national electricity supply, the sources of energy used by the electricity supply industry (ESI) to generate power are of crucial importance in analysing overall emissions. The benefits of electrification are discussed in Chapter Three.

For urban rail, the improvement in vehicle fuel economy will be mainly as a result of a growing number of LRT systems. Old networks, chiefly the London Underground, will exert a diminishing influence on total energy consumption.

Table 4.16 gives details of the projected trends in electrification and in energy consumption for rail travel in Scenario 1.

Table 4.16 Traffic distribution and power supply for the rail sector in Scenario 1

	1988	1990	1995	2000	2005	2010	2015	2020	2025
% of train km									
BR diesel	44	43	40	36	33	30	27	23	20
BR electric	42	43	46	50	53	56	59	63	66
LRT	14	14	14	14	14	14	14	14	14
Energy consumption per train km									
BR diesel (litres)	2.42	2.41	2.37	2.34	2.31	2.27	2.24	2.21	2.18
BR electric (kWh)	13.25	13.14	12.86	12.58	12.30	12.03	11.75	11.47	11.19
LRT (kWh)	12.50	12.21	11.46	10.71	9.97	9.22	8.48	7.73	6.99

4.6.4. Aircraft fuel economy

As explained above, an increasing pressure on airport capacity is likely to result in the use of larger aircraft, whose greater seating capacity results in a more efficient use of airspace. The specific fuel consumption of aircraft used for journeys within the UK is therefore expected to increase, as shown in Table 4.17, but to a lesser extent than the average seating capacity. The fuel consumption per seat kilometre is therefore expected to improve.

Table 4.17 Projected energy consumption for air travel in Scenario 1

Year	1988	1990	1995	2000	2005	2010	2015	2020	2025
Aircraft fuel consumption (MJ/km)	173	174	178	182	186	190	192	194	196

4.6.5. The electricity supply industry

With a growing proportion of rail travel electrified, the state of the electricity supply industry is increasingly important in evaluating emissions of CO₂. Presently most of Britain's electricity is derived from steam turbines powered by fossil fuels (principally coal). The efficiency with which fossil fuels are used to generate electricity is notoriously low: typically 70 per cent of the fossil fuel energy is lost during generation and transmission (Davies, 1991), mainly as a result of thermodynamic constraints.

Since the electricity supply industry was privatised, the future of nuclear power has been in question. It appears unlikely that nuclear capacity will be expanded on the scale once envisaged. The exploitation of renewable energy sources is likely to increase, though not to its full cost-effective potential.

Table 4.18 gives details of the energy sources used by the ESI up to the year 2025 in Scenario 1. The shares held by different fuels are based on scenarios produced by the Department of Energy (1990) for the future electricity supply industry. The scenarios are designed ‘... to illustrate how capacity might evolve, whilst recognising the very considerable uncertainties surrounding plant characteristics, future demand, and, not least, a privatised Electricity Supply Industry.’

Steam plant efficiency is expected to improve as new plant are built, although thermodynamic constraints will prevent major increases. Coal is expected to decline in favour of natural gas as a fuel for power stations, whilst nuclear and renewable energy taken together will decline.

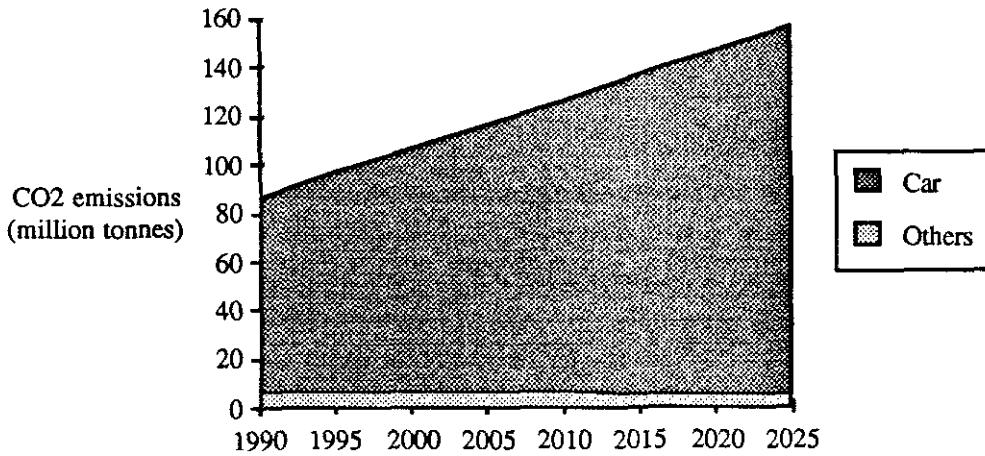
Table 4.18		Projected structure of the electricity supply industry								
	1988	1990	1995	2000	2005	2010	2015	2020	2025	
Fuels used by the ESI (% of electricity output):										
Coal	65.1	69.9	64.4	59.0	53.5	51.4	49.3	47.1	45.0	
Oil	12.1	4.3	4.2	4.2	4.1	3.8	3.6	3.3	3.0	
Gas	0.6	0.0	7.0	14.1	21.1	25.1	29.1	33.0	37.0	
Nuclear & renewable	22.2	25.8	24.3	22.9	21.4	19.8	18.2	16.6	15.0	
Steam plant efficiency	.34	.34	.35	.36	.37	.37	.38	.39	.40	

Source: author's estimates, based on Department of Energy, 1991.

4.7. Results of Scenario 1

The outcome of ‘business as usual’ in terms of passenger transport’s total CO2 emissions is given in Figure 4.3. Overall emissions increase from 87 Mt in 1990 to 157 Mt in 2025 - a growth of 80 per cent.

Figure 4.3 Total emissions of CO₂ from personal travel in Scenario 1



4.7.1. Reconciling transport emissions with the national target

The UK Government's policy on greenhouse emissions, as outlined in Chapter One, is to stabilise CO₂ emissions at their 1990 levels by the year 2000. Scenario 1 indicates that in the period 1990 to 2025, CO₂ emissions from passenger transport will increase by 80 per cent from 87 to 157 million tonnes (Mt).

Chapter Two has shown that transport operations contribute around 18 per cent to total CO₂ emissions (based on the 1987 figure of 16 per cent coupled with an increasing trend). Passenger transport contributes around 68 per cent of the transport total, or 12 per cent of national emissions.

Assuming that

(a) passenger transport develops in the 'business as usual' manner outlined in Scenario 1, and

(b) the nation as a whole achieves its present target of stabilising emissions at 1990 levels by the year 2000,

then it follows that all other sectors (industry, domestic, agriculture, commerce and freight transport) would between them need to achieve a five per cent cut in CO₂ emissions by 2000. The feasibility of such an option is addressed in the following chapter.

Chapter Five

MEASURES FOR REDUCING CARBON DIOXIDE EMISSIONS

5. MEASURES FOR REDUCING CARBON DIOXIDE EMISSIONS

If you want someone to clean the yard, go out and clean it.

And if they agree with you, they will come and help you.

Chief Oren Lyons

5.1. The need for policy changes

The preceding chapter has shown that a continuation of present policies, with no action taken to curb 'greenhouse' emissions, will lead to an increase of 90 per cent in CO₂ emissions from personal travel in Britain by the year 2025. In contrast, the current policy of the British government on CO₂ emissions is to stabilise production at the 1990 level by the year 2005. How can the two be reconciled?

A vital question at this point is to what extent different energy sectors (domestic, industrial, transport and so on) should curb their individual emissions in order to contribute to a particular national target. The cost of stabilising greenhouse emissions varies between different sectors, so some method of allocation must be devised in order to minimise the overall cost.

On this question the House of Commons Energy Committee (1991) holds the view that:

A large increase in the transport sector's CO₂ emissions balanced by disproportionately heavy reductions in other sectors would not be a rational way of achieving the emissions target, and the Department of Transport should draw up a comprehensive policy ... to try to prevent this occurring.

(House of Commons Energy Committee, 1991.)

No such policy statement has yet been produced by the Department of Transport in response to this recommendation. Instead, the government acknowledges somewhat generally 'that the transport sector will have to play its part in meeting any greenhouse gas targets' (ibid).

The German government, by contrast, has performed the necessary allocation exercise and produced figures for the cuts in emissions that various sectors will need to make. In order to achieve a 25 per cent cut in overall CO₂ emissions, some sectors will be required to make

cuts as large as 39 per cent, whilst transport will be required to achieve just nine per cent (Warren, 1990).

In the absence of such a detailed strategy in the UK, this study notes the need for a variable response from the transport sector, depending on what target is allocated to it. On the basis of the German plan, it is assumed that transport would not be required to achieve reductions in emissions on behalf of other sectors, although the reverse may apply. This chapter examines the policy measures that are available for controlling CO₂ emissions from personal travel and which would make a substantial contribution to an overall CO₂ reduction target. The greatest reduction in emissions considered by this study is the 60 per cent cut proposed by the IPCC (Houghton et al, 1990).

5.2. Approaches to controlling greenhouse emissions from transport

There are two broad approaches to controlling greenhouse emissions from personal travel, within each of which is a range of possible measures:

Approach A: 'technical fixes'

- reducing CO₂ emissions within the existing pattern of travel and modal distribution, by:
 - more efficient use of fossil fuels;
 - switching to energy sources that produce less, or no, net CO₂.

Approach B: altered travel patterns

- rearranging the present distribution of travel between modes to one that uses less energy, by:
 - modal shifts towards more efficient transport types;
 - reducing the volume of travel.

The two approaches are by no means exclusive, but represent two distinct philosophies. Approach A tackles the problem of greenhouse emissions by technological means alone, without altering the nature and volume of transport demand. Approach B is politically more

difficult, aiming to modify the volume and the characteristics of travel itself. A successful strategy may need to draw upon policies from both categories.

5.2.1. Policy ‘levers’

A continuation of present policies, where they exist, may be viewed as a ‘business as usual’ scenario: no changes will take place other than a continuation of present trends. If current trends are to be broken, there must be some stimulus for this to happen.

There has recently been evidence of a shift in consumer behaviour towards more environmentally sound practices, a phenomenon termed ‘green consumerism’. This is the effect whereby the public pays a higher price for a product or service because of its environmental qualities. In effect, consumers have begun to attach market values to the environmental attributes of products and services.

Former UK environment secretary Christopher Patten (1989) has described the effect thus:

There is an ethical dimension which finds powerful expression in the behaviour of individuals.... The green consumer and the green investor are beginning to emerge as a significant force in the market place.

There is, however, a flaw in green consumerism as a market-based instrument for environmental protection. Consumers attach values only to those environmental assets which they know about and with which they are concerned. Many forms of environmental damage may be overlooked by the consumer because either information is incomplete or concern is lacking. Concern for environmental issues does not always correspond to their importance. Cairncross (1991) cites two examples:

Individuals may drive their cars to work, rather than take a bus; companies may use chlorofluorocarbons in their commercial refrigerators. In both cases, the costs to society at large, from traffic fumes in one case and from a damaged ozone layer in the other, exceed any private cost to individual or company. That is inefficient. Governments need to step in to align private costs with those to society at large.

Environmental benevolence is not a sufficiently powerful instrument for change. Instead, policy ‘levers’ must be used to bring about changes in behaviour. To reduce greenhouse emissions, as in other areas of environmental concern, there is some debate as to what the stimulus for change should be. There are three broad categories:

- ❑ *Government regulation*, whereby standards relating to environmental protection are set nationally or internationally. Society as a whole, or sectors thereof, are legally bound to observe the prescribed limits. This approach has also been termed ‘command and control’;
- ❑ *Market-based instruments*, in which the state uses market forces by modifying the price of environmentally sensitive activities; the ‘polluter pays principle’ applies, whereby there is no regulation of environmental damage but instead a cost is assigned according to the severity of the damage;
- ❑ *Investment* in less carbon-intensive forms of transport and infrastructure, including financial support, land-use planning and other forms of assistance.

The following sections will examine the general principles of these three different policy levers, and then examine in detail their applicability in reducing CO₂ emissions.

5.2.2. Government regulations

In many cases, environmental goals can be achieved through the application of government regulations. These may be applied to businesses, industries or consumers, and they take the form of a mandatory requirement to follow prescribed procedures. For example, the EC legislated in 1989 that all new cars sold in Europe must be fitted with three-way catalytic converters from 1993; similarly, the British MOT test now requires that car engines be tuned so as to limit exhaust emissions to a specified level.

Cairncross (1991) points out that regulations are not always the best way to solve environmental problems. They tend to demand the same action from all parties regardless of the cost to the individual. For example, some companies (particularly larger ones) are better placed to respond to new regulations than are others. Regulations may be seen as an inequitable means of achieving environmental targets. For example, a catalytic converter imposes a proportionately larger cost penalty on a cheap car than it does on a larger, more expensive model.

5.2.3. Market-based instruments

Market-based instruments may be used as an alternative, or in addition, to regulations. Market forces can be harnessed to achieve environmental goals or to compensate for environmental impacts, directly or indirectly.

There are traditional arguments in favour of a market-based approach to environmental protection, many of which were updated in 1989 by the publication of 'The Pearce Report' (Pearce et al, 1989). The authors proposed that the natural environment be subjected to traditional market mechanisms, using a cost-benefit approach. This would require the assignment of monetary values to environmental assets. Accordingly, the price of all goods and services would reflect the full environmental costs involved in their provision.

In many cases, market-based measures are already in operation in the form of revenue-raising taxes, and a manipulation of the existing taxation structure could address environmental goals. Transport, and in particular road transport, is subject to a variety of taxes, which could be adjusted to provide market-based policy levers. Potter (1992a) points out that very few transport taxes were instituted with policy goals in mind:

Historically, fiscal policies have only been used to raise money for government finances and as part of broad economic and employment intervention. Only very rarely have fiscal measures been used to promote transport policy goals, even though their impacts on transport are substantial.

If existing taxes could be redirected with policy goals in mind, environmental targets could be addressed without affecting the overall tax burden.

ENVIRONMENTAL TAXATION

A market-based approach to environmental protection can be found in the principle of 'environmental taxation', which would replace existing fiscal arrangements by taxes that reflect environmental impacts. The overall level of taxation would be the same before and after the reform (fiscally neutral). Whitelegg (1991) explains the principle, which he terms 'ecological taxation reform' or ETR:

Ecological taxation is based on the principle that taxes should fall most heavily on those activities and materials that produce pollution and/or environmental damage. Such taxes would replace taxes on labour and capital, would be phased in over 30 years, and would exert a steering effect on the economy so that environmentally damaging activities (e.g. carrying freight by lorries) would gradually be replaced by environmentally-friendly alternatives (e.g. rail). ETR is not an additional tax: it is a replacement tax. The total taxation burden would remain constant.

THE CARBON TAX

In the context of energy consumption, environmental taxation can take the form of a *carbon tax*, paid by consumers of fossil fuels in proportion to the amount of carbon they use. This

means that carbon-based fuels would be priced in such a way as to internalise the environmental cost of increased radiative forcing (Barrett, 1991). In September 1991 the European Community announced a form of carbon tax, in the shape of a proposed energy tax. The EC tax would in fact be a hybrid between a carbon tax and a tax on energy: half of the revenue would be based on the energy content of fuels, and the other half on the carbon content. It would involve \$10 being added to the cost of a barrel of oil by the end of the century (Gardner, 1991).

The exact level at which a carbon tax should be set is subject to a number of variables, which when combined lead to considerable uncertainty. The price of crude oil can fluctuate significantly, even without the addition of a carbon tax. Furthermore, estimates of how the demand for fuel will respond to a given increase in price are far from certain. Small changes in the assumed elasticity of demand can have a profound influence on the required level of carbon tax.

Barrett (1991) quotes widely-varying estimates of the savings that different levels of carbon tax can achieve, and concludes that:

While it is difficult to compare the estimates from one study with those of another, the qualitative story is pretty clear. To lower CO₂ emissions very substantially would require a large carbon tax - larger, certainly, than the taxes already implemented, or for which there exist firm proposals.

Accordingly, there is a strong argument for an 'iterative', target-led approach, whereby a carbon tax is set at a level that is judged to be approximately suitable, then adjusted after a period of years on the basis of the observed response. This principle is expounded by Potter (1992a), who holds the view that '... using the fiscal system to achieve non-fiscal goals is such an uncertain area that it is expedient to introduce measures and adjust them as their effectiveness is determined.'

TRADEABLE PERMITS

As indicated earlier, different individuals have a varying ability, or desire, to comply with environmental targets. The principle of tradeable permits is that individuals who exceed the required reduction in environmental damage can 'sell' their excess to individuals who have not managed to do so. The government might issue 'pollution permits' to individuals, companies or establishments, which can then be bought and sold at an agreed price. For example, companies that do not wish to comply with government pollution targets can 'buy' additional permits from another company. Companies that reduce their pollution output will have spare permits that they can sell to the polluters.

Tradeable permits may be used to introduce an element of flexibility into a market-based programme of environmental protection, and although somewhat regulatory in nature, they work via the market mechanism of altering the supply side of the supply-demand balance.

Permits may be used on a variety of scales, from regional to international. Such a programme has been built into the legislation requiring car manufacturers to sell a certain proportion of 'clean' vehicles in California. (Further details are given later in the chapter.) For a fuller discussion of the principles, see Markandya (1991).

REVENUE SUBSIDY

Another form of market-based instrument in transport provision is the regulation of prices through the use of grants. Governments can, in addition to imposing taxes, subsidise activities that will reduce environmental impacts. In transport, this might entail a subsidy of the revenue raised by public transport operators from fares, thereby allowing lower and more competitive prices to be set.

Subsidised fares have been widely used in the past, generally for non-environmental reasons. They are an expensive means of achieving transport goals, and traditionally they have been politically contentious. The Greater London Council's 'Fares Fair' policy of the early 1980s was the focus of a major conflict between the council and the Conservative government, which ultimately led to the abolition of the GLC and the metropolitan councils. More recently, the Conservative government's objective of reducing or removing altogether the revenue subsidy given to British Rail sectors has raised vociferous opposition. (See, for example, The Labour Party, 1990.)

Reductions in public transport fares do not simply result in transfers away from the car to other modes. A major effect is the generation of additional trips among people who were already using public transport. On both political and environmental policy grounds, revenue subsidy needs to be used with caution.

5.2.4. Investment

Alongside regulations and market mechanisms, the role of *investment* in reducing travel-based emissions of CO₂ should be considered. The term 'investment' is taken to mean the allocation of government funds to transport projects in order to facilitate capital spending programmes such as expanded infrastructure, increased capacity and improved services. Investment can lead to increased patronage, since the transport operator is able to offer an improved service or a greater capacity, or both.

Recently, investment capital for formerly public sector-financed transport developments has been forthcoming from a number of private companies. Privately-funded projects have included the Channel Tunnel rail link and a contribution to the Jubilee Line extension in east London, as well as a number of proposed toll bridges and roadbuilding schemes.

5.2.5. Summary

Regulations, market mechanisms and investment can all contribute to curbs on CO₂ emissions. In general, market-based incentives have greater flexibility than do regulations. Individuals who are unable or unwilling to comply with standards can instead pay a levy, whilst those who exceed the standard are rewarded.

It is impossible to make a generalised choice between regulations and market mechanisms as a solution to environmental problems. Different sectors warrant different solutions, and the choice between regulations and MBIs must be made on a case-by-case basis. For example, the building industry is likely to respond better to energy-saving regulations than to energy taxes, since the value of saved energy is generally small when compared with the cost of constructing a house. The transport sector, on the other hand, has a relatively rapid turnover of vehicles, and can respond quickly to financial incentives.

The three types of policy are now considered in the context of Approaches A and B. As explained earlier, Approach A consists of technological measures to promote fuel economy and alternative fuels, whilst Approach B aims to influence the volume and modal distribution of travel.

5.3. Measures to promote fuel economy

When considering the possible effect of fuel economy improvements upon CO₂ emissions, it is necessary to focus almost entirely on cars. This is because

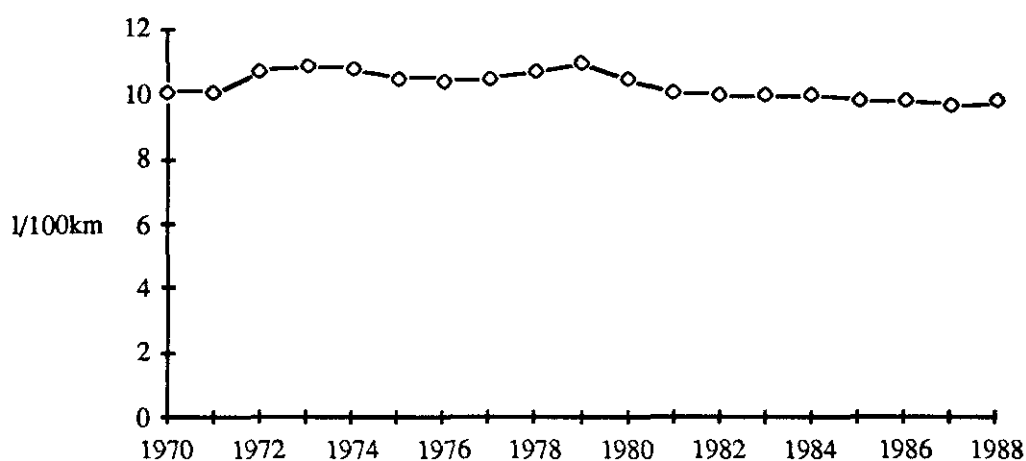
- Cars are the largest producer of CO₂ within the passenger transport sector; Chapter Two has shown that they are responsible for around 90 per cent of emissions. Policies that address this subsector will thus be the most effective overall;
- The potential for improving fuel economy in cars is far greater than in other modes. In particular, public transport vehicles tend to have a fuel economy that is the maximum cost-effective level. In many cases, the cost-effective level of fuel economy does not differ greatly from the maximum technical

fuel economy. Cars, on the other hand, have a considerable potential for cost-effective improvements in fuel economy.

It has been shown in Scenario 1 that a small ongoing improvement in car fuel economy is insufficient to curb CO₂ emissions, since the growth in traffic volume will more than cancel out such a small gain in efficiency. To begin to tackle emissions, more significant improvements in fuel economy are required.

Green consumerism has made little impact to date on the market for vehicles. In the climate of low oil prices that has prevailed in the last 20 years, consumers clearly value other attributes, such as comfort, vehicle size, performance, image and so on more highly than they do the benefits of conserving energy. Figure 5.1 shows that average car fuel economy in the UK has hardly changed in the last 20 years, despite advances in vehicle efficiency.

Figure 5.1 Average car fuel consumption in the UK, 1970-88



Source: Schipper, 1991

It is possible that the potential of green consumerism for promoting fuel economy could be improved by the introduction of better product labelling, since lack of information is one of the reasons why public benevolence is an unreliable instrument for policy goals (see 6.2.1). At present, car buyers are encouraged to restrict their consideration of environmental attributes to whether the vehicle runs on unleaded petrol or is fitted with a catalytic converter. Other environmental aspects such as fuel consumption tend to be downplayed in favour of qualities such as vehicle size, comfort and performance.

But poor information is only part of the picture, since consumers may not make 'environment-friendly' transport choices even when equipped with perfect knowledge of the issues involved. Positive incentives are required in order to promote sales of more economical vehicles.

A variety of measures are available for promoting fuel economy as a consideration for the car purchaser. These tend to be limited to regulations and market mechanisms, the first two policy levers described in 5.2.1.

5.3.1. The role of regulations in promoting fuel economy

In the USA, experience in the last two decades suggests that regulations can be effective in stimulating improvements in vehicle fuel economy. In the mid-seventies, the USA government established the notion of Corporate Average Fuel Economy (CAFE), which represented the average fuel economy of new vehicles being sold in the USA by each car manufacturer. Legislation was passed to encourage manufacturers to improve their CAFE rating. Greene (1989) summarises the programme as follows:

Following a tripling of world oil prices in 1973-74, the US Congress passed the Energy Policy and Conservation Act of 1975 establishing mandatory fuel economy standards for automobiles and light trucks. Beginning at 18 miles per gallon¹ [13.1 l/100km] in 1978, the passenger car standards increased to 27.5 mpg [8.6 l/100km] in 1985.

Figure 5.2 illustrates the trend in fleet fuel economy in the USA since 1970. The average fuel economy of cars entering the market has doubled, whilst the fuel economy of cars in use has improved by almost as much. There is a time-lag between the fuel economy of new cars improving, and the improvement being reflected in the fuel economy of the car stock as a whole.

Greene (1989) addresses the question of the extent to which the CAFE legislation was responsible for the marked improvement in fleet average fuel economy, and whether increases in fuel price may have been a more significant motivation.

His approach is to divide car manufacturers into two categories: firstly, those for whom the regulations required an increase in CAFE (mainly domestic car makers); and secondly those who were largely unaffected by the regulations, since their cars were already exceeding the minimum standard set by the government (mainly overseas manufacturers). The two

¹ Refers to the North American gallon, equivalent to 0.8321 imperial gallons or 3.785 litres.

categories are termed 'constrained' and 'unconstrained' respectively. Examining the effect of fuel price on the fuel economy of new cars in either category, the study shows that

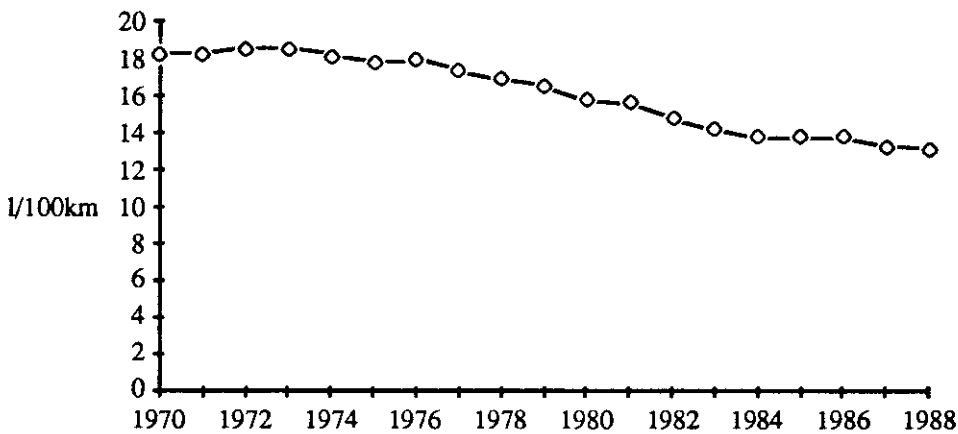
Constrained-carmaker mpg was twice as sensitive to rising prices as falling prices, suggesting that manufacturers took some actions to counteract the downward pressure of falling prices in order to meet the targets. Unconstrained manufacturers, in contrast, responded slightly more to falling than to rising prices....

These results [among others] support the assertion that the EPA CAFE standards were effective in influencing many carmakers to plan for and achieve dramatic increases in new car fuel economy.

(ibid)

Further, qualitative evidence for the effectiveness of the standards comes from the observation that average fleet fuel economy in the USA continued to increase even during periods of falling fuel price.

Figure 5.2 Average car fuel consumption in the USA, 1970-88



Source: Schipper, 1991.

SPEED LIMITS

Chapter Three demonstrated a correlation between fuel consumption and speed for a typical car (see Figures 3.4 and 3.5). At the upper end of the speed range, fuel consumption increases broadly with the square of speed, in accordance with equation 3.1.

In Britain the national speed limit is 70 mph on motorways and dual carriageways. No vehicle is permitted to exceed this speed on any road. However, there is evidence of widespread flouting of this regulation: a Department of Transport survey in 1991 indicated that 72 per cent of cars at free-flowing locations on motorways are exceeding 70 mph (Department of Transport, 1991b).

A significant volume of fuel could be saved by fully enforcing the 70 mph national speed limit. It is shown in Appendix 3 that a full enforcement of the 70 mph speed limit could result in the saving of 500,000 tonnes of petroleum by cars alone, corresponding to the elimination of 1.5 million tonnes of CO₂.¹ The elimination of excessive speeds can also reduce congestion at bottlenecks, thereby reducing the amount of fuel lost as a result of inefficient driving in such conditions.

Measures to bring about the better enforcement of speed limits could be deployed almost immediately, but would incur costs in terms of additional policing time and surveillance technology. Roadside equipment is available for monitoring vehicles electronically, and photographing those that exceed a predetermined speed. Such devices are now permitted by law, but require capital investment by the Government. A single camera costs around £10,000, but there is evidence that 'dummy' cameras can also be effective in deterring drivers from speeding (BBC, 1991).

5.3.2. The role of market measures in promoting fuel economy

The principal drawback of fuel economy regulations is that they may do nothing to reduce overall petroleum consumption. Even though new cars may be more economical than before, there is no incentive to reduce the overall amount of fuel actually consumed. In fact, consumption may increase: it has been argued that the CAFE standards may contribute to increased car usage: better fuel economy makes motoring cheaper, and thus encourages greater use of cars (Marshall, 1991). Petroleum consumption by cars in the USA has shown a gradual increase since 1970 despite improvements in individual vehicle fuel economy, the main factor at work being an increase in car mileage.

Certain market-based schemes, on the other hand, could overcome the price effects that increase travel demand. For example, the use of *fuel taxes* to promote fuel economy would mean that the amount spent on fuel (pence per km) could remain the same, with the increased

¹ Further savings could be made by enforcing the law on roads with a 60 mph speed limit. However, there are no data available indicating the amount of speeding, and thus the fuel consumption excess, on these roads. This analysis is restricted to traffic that is subject to the 70 mph speed limit.

fuel price being counteracted by improved fuel economy. There would thus be no net price effect to stimulate a growth in vehicle mileage.

The essence of the market-based approach is that there are no regulatory standards, but instead financial incentives are offered to consumers who favour a more economical use of energy, and penalties are imposed on those who opt to use more than they need. Alternatively, a combination of regulatory and market measures could be used.

REARRANGING TRANSPORT TAXES

Rearranging the present transport taxation system to include environmental taxation principles could encourage the use of more economical vehicles. Presently, Vehicle Excise Duty (VED) is payable at a flat rate of £100 per year for private cars. By charging VED at a rate that is related to the fuel economy of the car, it is possible to provide consumers with a clear incentive to purchase more economical vehicles, with no effect on overall revenue income.

Other taxes include the Special Car Tax, charged at five per cent of the car's value, and Value Added Tax (VAT), charged at 17.5 per cent. These too could be varied according to fuel economy.

Cars provided by companies for their employees form a major sector of the British car stock, and taxation on their use has historically been lower than tax on income paid as cash (see 3.2.5). Potter (1992a) has proposed changes to the fiscal arrangements relating to company cars. These include increases in the *scale charges*, which represent the value assigned to cars for taxation purposes. On average a 1.4-litre car attracts a scale charge that is 88 per cent of the car's true value; for a car in the range 1.4 to 2.0 litres, the proportion is 77 per cent, whilst for a car of over 2 litres in capacity the scale charge averages just 61 per cent of the true value.

As 'genuine need' company car users tend to have smaller cars and 'perk' users larger ones, the system works to the advantage of income-in-kind company car users and against company car users with valid travelling needs. The taxation of larger cars could be increased relative to the rates on smaller cars, to discourage the purchase of uneconomical vehicles, and would also benefit valid company car users.

Potter also suggests that company cars be taxed according to their fuel economy, using the standard figures available from the Government for all models. Scale charges might be removed altogether and replaced with a system of electronic monitoring of vehicle movements: drivers would then be taxed only on mileage undertaken for private business

(ibid). Given that the majority of new cars are now purchased by companies, this is an important sector to target for fiscal reform.

As indicated earlier, fuel economy improvements do not necessarily yield reductions in fuel consumption. Motorists may tend to use their cars more as a result of the reduced fuel costs associated with more economical vehicles (Von Hippel and Levi, 1983). To remove this feedback effect, VED and other 'flat rate' taxes could be removed altogether and the revenue collected instead through increased fuel taxes. The use of fuel taxes as a means of raising revenue encourages consumers not only to purchase more economical vehicles but also to reduce their overall travel volume.

Any changes to the existing taxation structure can be made 'revenue neutral', so that the overall tax yield is unchanged.

'FEEBATE' SCHEMES

Another example of a market-based measure that uses restructured taxation to encourage fuel economy are 'feebate' programmes. These are revenue-neutral schemes whereby consumers who purchase economical vehicles are given rebates, whilst those who do not are charged fees. As before, there are no mandatory standards, but consumers are required to pay the cost of 'undesirable' practices.

A feebate scheme has been proposed in California. The scheme is called 'DRIVE +' (Demand-Based Reductions in Vehicle Emissions Plus Improvements in Fuel Economy), and addresses all forms of gaseous emissions from vehicles including CO₂. DRIVE + would impose sales tax surcharges on purchasers of large or polluting vehicles, and the proceeds would be used to fund rebates for purchasers of less polluting vehicles. The entire programme would be revenue-neutral and require no support from government (Levenson and Gordon, 1990).

A similar 'feebate' scheme was established in Ontario, Canada in August 1991. The original plan proposed a system of sales tax that was related to the fuel economy of the vehicle, with the least economical category attracting a tax of \$7,000. Pressure from the motor industry resulted in a modified version of the scheme being implemented. The tax rates for mid-range vehicles were made less severe, although the maximum penalty remained at \$7,000. The revised scheme offered a rebate of \$100 to purchasers of the most economical vehicles. Table 5.1 gives details of the programme.

A scheme similar to the Ontario programme could be established in Britain, based on the official test figures for new-car fuel economy. Potter (1992a) suggests that car purchase tax, VED and VAT might all be related to vehicle fuel economy, with a system of rebates and

surcharges. This could be done using either a standard 'minimum' fuel economy or a banded structure similar to that devised in Ontario.

Table 5.1 Taxation of passenger vehicles under the Ontario programme

Highway fuel economy (l/100km)	Tax / (Rebate)
Less than 6.0	(\$100)
6.0 - 8.9	\$75
9.0 - 9.4	\$250
9.5 - 12.0	\$1,200
12.1 - 15.0	\$2,400
15.1 - 18.0	\$4,400
More than 18.0	\$7,000

Source: Laughren, 1991.

INTERNATIONAL EXPERIENCE WITH TRANSPORT TAXATION

There is clearly a wide range of possible fiscal measures to stimulate better fuel economy in the car sector, but to date there has been only limited experience of such policies in action. Japanese experience with vehicle pricing supports the view that market mechanisms can stimulate rapid changes in the vehicle fleet. In 1976, *kei* (lightweight) cars were exempted from on-street parking charges in Japan. (*Kei* cars have a maximum engine capacity of 550cc and a maximum length of 3.2 metres.) By 1988 sales of *kei* cars had soared, with 1.8 million vehicles in this category being sold per year. Conversely, the market for these vehicles began to decline in 1989 following the abolition of the parking exemption (The Economist, 1990).

In Italy, a number of economy-related tax measures have been adopted. The Italian equivalent of VAT is charged at 19 per cent on cars whose engine capacity is less than 2000cc (2500cc for diesels), and above this threshold the rate is doubled to 38 per cent. In addition, the property tax that is payable every year on cars by their owners is related to 'fiscal horsepower', similar to the insurance groups into which cars are categorised in Britain. Table 5.2 shows how the graded taxation works. These market-based policies, similar in effect to 'carbon taxes', have had a significant effect upon the fuel economy of private cars. Car fuel economy in Italy since 1970 has been better than in any other European country. In 1988, it was 23% higher than in the UK (Hughes, 1991).

Table 5.2 Property tax payable on cars in Italy

Fiscal horsepower	Approximate engine size (cc)	Property tax (1000 lire)	
		Petrol-engined	Diesel-engined
5	500	36	411
10	850	55	429
15	1300	164	539
20	2000	334	1009
25	2500	506	1349

Note: the property tax on petrol cars is less because petrol is taxed more heavily than diesel.
Source: Liberati, 1991.

Finally, another example of taxation measures used to promote fuel economy can be found in the Isle of Man, which lies outside the government of the United Kingdom. The annual vehicle licence fee is related to vehicle engine capacity, according to six categories. These are detailed in Table 5.3. Although the differential between different engine capacity classes is not great, the Isle of Man scheme nevertheless provides an example of one type of system that could be operated in Britain.

In summary, there is a broad spectrum of market mechanisms that might be used to promote vehicle fuel economy. The present system taxes car ownership and takes little account of car usage and its environmental impacts. The measures described above provide a means of incorporating environmental considerations into the taxation system.

Table 5.3 Annual licence fees for cars in the Isle of Man

Engine capacity (litres)		Licence fee
More than	Not more than	
	1.0	£38
1.0	1.2	£45
1.2	1.8	£50
1.8	2.5	£65
2.5	3.0	£90
3.0		£95

Source: Pinkerton, 1991

5.3.3. Improving fuel economy: regulations or market incentives?

The improvement in average fuel economy that has taken place in the USA since 1975 is a testimony to the effectiveness of regulations. Other successes for regulations include the phasing-out of CFCs in accordance with the Montreal Protocol (Chapter One) and the adoption of EC-wide vehicle emissions standards in 1989 (Chapter Two). In other areas market mechanisms may be preferable, because:

- ❑ CAFE-type schemes do not encourage manufacturers to go beyond the level of fuel economy required by the regulations;
- ❑ In the present political climate, market-based solutions are more likely to be acceptable than regulations; the present government favours free-market operations rather than regulated programmes. Market-based instruments can cost considerably less to the Government, particularly if a revenue-neutral scheme is adopted;
- ❑ Fuel economy regulations can be successful in improving specific energy consumption (SEC), but may not necessarily contribute to reduced energy consumption overall. As shown above, reduced fuel costs can lead to increased car usage. A market-based scheme, on the other hand, can charge motorists according to the distance that they travel, thus taxing *overall* fuel consumption rather than just SEC.

A detailed analysis by Leone and Parkinson (1990) has examined the CAFE regulations in the USA, and demonstrated that the situation is by no means clear-cut. The extent to which the improvements in car fuel economy are attributable to the CAFE standards will probably never be understood with confidence. However, the main criticism of the American approach is that market measures, in the form of fuel taxes, could have achieved the same result at a fraction of the cost:

A market-based approach to energy conservation is superior in effectiveness to regulation of the corporate average fuel economy (CAFE) of new vehicles. Market incentives to encourage energy conservation cost society far less than command and control regulations like CAFE.

(Leone and Parkinson, *op. cit.*)

This study acknowledges that both market mechanisms and regulations have a role to play in achieving improvements in fuel economy. However, market mechanisms are viewed as more appropriate, for the reasons outlined above.

5.4. Measures to promote alternative fuels

5.4.1. A further technological solution

In addition to improvements in vehicle fuel economy, *alternative fuels* represent another means of reducing CO₂ emissions. The term 'alternative fuels' is used here to represent not only different forms of fuel, but also novel engine types. In accordance with this study's emphasis on primary energy consumption, an examination is made below of the processes by which the fuels are produced and supplied to the point of use.

This section examines in detail the options that are currently available for alternative forms of propulsion, and the policies that might be used to promote these technologies.

5.4.2. Motives for the development of alternative fuels

Alternative fuels have been advocated worldwide for various reasons, and it is possible to identify three distinct motives:

- Conserving oil supplies, or reducing dependence on imported oil;
- Reducing air pollution in areas of high traffic density;
- Reducing emissions of 'greenhouse' gases.

Traditionally, the first two items have been the main incentive for developing alternative fuels. For example, in 1975 Brazil embarked upon a programme aimed at replacing most of its imported gasoline with ethyl alcohol, distilled from domestically grown sugar cane (Weiss, 1990). Similarly, Canada and South Africa have constructed plant for *manufacturing motor fuels from coal and tar sands*. New Zealand has replaced almost half of its petrol consumption with natural gas (Sperling and DeLuchi, 1989). Meanwhile Southern California, gripped by a worsening air pollution problem, has adopted regulatory legislation that will require 40 per cent of new cars to run on 'clean' fuels by 2000, and 100 per cent by 2008 (South Coast Air Quality Management District, 1989).

Many of the technologies whose development has been stimulated by alternative fuels programmes are also relevant from the perspective of reducing CO₂ emissions. However, it is vital that a proper evaluation be performed, so that valid CO₂ abatement technologies may be separated from those that will give no benefit in terms of reduced greenhouse emissions. The following sections describe the technological options available for alternative methods of propulsion.

5.4.3. Alternative fuels for different travel modes

In principle, alternative fuels can be applied to all motorised forms of transport. For example, the rail sector in Britain has undergone radical changes in its energy supply in the last hundred years. Rail transport has progressed from coal to diesel as the dominant fuel, and more recently electric traction has taken over a large portion of railway operations.

Aircraft too are capable of running on fuels other than petroleum. Hydrogen, natural gas and alcohol fuels are among the options available, though all of these are beset by serious engineering difficulties (see 5.4.12).

Emissions of CO₂ from transport within Britain are produced overwhelmingly by road transport. Figure 2.2 showed that road vehicles account for 95 per cent of CO₂ emissions from passenger and freight operations. Alternative fuels will therefore have a much greater impact if applied to road transport than if introduced to rail or air. The emphasis of this section is therefore on alternative fuels for road vehicles. Described below are alternative forms of energy that might be deployed in road passenger transport, including cars, buses and coaches.

5.4.4. Electric (battery) storage

Electric vehicles have been in operation for many years in Britain, mostly in the form of electric milk delivery vehicles. They store electricity in batteries that are carried aboard the vehicle, and which are charged from the mains supply when the vehicle is not in use. The principal disadvantage of electric traction is the limited range of the vehicle between charges.

Recent legislation in the USA has prompted renewed interest in electric vehicles. The 1990 Clean Air Act Amendments (CAAA) include a programme that requires the car fleets in a number of heavily-polluted areas to contain a percentage of low-emission vehicles. Electric vehicles are classified as 'zero-emissions vehicles'. In addition, the State of California has ruled that car manufacturers must, from 1994 onwards, comply with increasingly strict pollution specifications that will involve the sale of a minimum number of electric vehicles (Chang et al, 1991).

The first purpose-built electric car to be produced by a major manufacturer was the *Impact*, developed by General Motors and launched in January 1990. The *Impact* is powered by conventional lead-acid batteries, and overcomes the problem of poor range by employing lightweight materials and a highly aerodynamic shape.¹

¹ The drag coefficient of the *Impact* is 0.19

An increasing number of car manufacturers have joined the race to develop electric cars suitable for the new USA market. Peugeot, Volkswagen, BMW, Renault, Lada, Daihatsu and Nissan have produced prototypes which they claim can provide levels of range and performance comparable with those of conventional internal combustion (IC) engined vehicles. Nissan's design makes use of advanced nickel-cadmium batteries, whose smaller mass leads to significant energy savings overall. BMW's prototype, the E1, uses a sodium-sulphur battery. Both types have better performance characteristics than a conventional lead-acid battery, but cost around six times more at present.

The USA legislation foresees electric vehicles as a replacement for many IC-engined vehicles in current use. The benefits of electric traction are most noticeable in an urban environment, where frequent stops are made. In this type of driving, IC engines (particularly spark-ignition engines) are at their least efficient. Furthermore, the limited range of electric vehicles is less of a problem in low-speed, short-distance applications. In addition, there are other benefits of using electric vehicles in cities, related to air quality, noise and general intrusion.

The nature of the Californian legislation, which requires low-emission vehicles to be used in urban areas but places no restriction on the type of vehicle used elsewhere, means that *hybrid* cars are likely to find a market niche. Hybrids are typically equipped with both an electric motor and an IC engine: the electric motor is used for driving in town, while the heat engine is used for the more demanding long-distance travel. The batteries may be charged either from the mains or from the car's IC engine.

Already there are a number of prototype hybrid cars. These include an adapted Volkswagen Golf and a vehicle called the LA301. Developed in Britain by Clean Air Transport, this two-door hatchback uses a 650cc petrol engine and an electric motor (Schoon, 1991).

As explained in Chapter Two, electricity is not a primary fuel, but a medium for storing energy that is derived from some other source. The means for generating electricity are varied, and include fossil fuel-fired power stations, nuclear stations, and renewable sources of energy (wind, wave, solar and hydroelectric). The level of CO₂ emissions is crucially dependent upon the source of primary energy.

Vehicles powered by non-fossil electricity (nuclear and renewable) offer a complete elimination of greenhouse emissions¹, whilst electricity from natural gas also offers a benefit as a result of its low carbon content. In terms of CO₂ production, electric vehicles using the present USA power supply offer no advantage over IC-engined vehicles, and will become even less attractive if further improvements in the fuel economy of IC-engined cars take

¹ It should be noted, however, that nuclear stations use a large amount of fossil fuels in their construction, a consideration that needs to be taken into account in any CO₂ reduction strategy.

place. Electricity from coal plants would actually worsen greenhouse emissions (see 5.4.13 below).

The same analysis can be performed for Britain as for the USA, where the mix of fuels in the electricity supply industry is approximately the same. A report by the Society of Motor Manufacturers and Traders contains the following analysis:

Although the process of electric power generation is somewhat more efficient than an internal-combustion engine it is still only of the order of 35 per cent. However, the *overall* (power station fuel to road wheels) system for operation of an electric vehicle includes further losses. The electricity distribution system to the consumer is about 90 per cent efficient and assuming a conventional battery charger system, the charger is about 80 per cent efficient and the battery 85 per cent. Finally, the electric vehicle engine (motor) and transmission are somewhere between 60 and 90 per cent efficient. Taking an average for this of 75 per cent, then the overall energy efficiency of the system is around 16 per cent. Use of regenerative braking can give a 10 per cent improvement in the efficiency of the motor/transmission system, giving an overall figure of 17 to 18 per cent. Compared to quoted *overall* (crude oil to road wheels) energy efficiencies of 18 to 20 per cent for petrol vehicles, and a further two per cent for diesel, this strongly suggests that *the use of electric vehicles would not reduce CO₂ emissions where the electricity was produced by fossil fuel combustion* [author's italics].

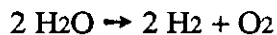
(SMMT, 1990)

In conclusion, electric vehicles can offer reduced greenhouse emissions provided that the electricity is provided primarily by non-fossil sources together with natural gas.¹ Given the present-day mix of fuels used to generate electricity, electric vehicles are not capable of providing reductions in greenhouse emissions. This is especially true if conventional, IC-engined vehicles are assumed to become more economical than the current average. A viable future for electric vehicles will require a substantial shift away from carbon-intensive fuels in the electricity supply industry.

5.4.5. Hydrogen and fuel cells

Like electricity, hydrogen is not a primary fuel but a means of storing and transporting energy. Hydrogen can be produced by decomposing water into oxygen and hydrogen according to the equation

¹ In Britain, CO₂ emissions from natural gas-fired power stations will be reduced with the introduction of more efficient combined-cycle generation.



where both products are in the gaseous state. The most promising means of achieving this is through the electrolysis of water. The electricity used in this process can be derived from a variety of sources including fossil, nuclear and renewable energy. The energy efficiency of electrolytic production is typically low, between five and 25 per cent (Sperling and DeLuchi, 1989). Alternatively, hydrogen can be manufactured directly from fossil fuel feedstocks.

Hydrogen fuel can be burned in a conventional IC engine, or else used to power a *fuel cell* (see below). In both cases, the principal waste product is water vapour. Emissions of other pollutants, with the exception of nitrogen oxides (NO_x) from IC engines, are negligible.

Prototype hydrogen-burning vehicles have been developed by the German car manufacturers BMW and Daimler-Benz, although these have been conversions of existing production models rather than purpose-built hydrogen-powered vehicles. The BMW conversion runs on liquid hydrogen, stored at -253° centigrade, and has a range of 300 km.

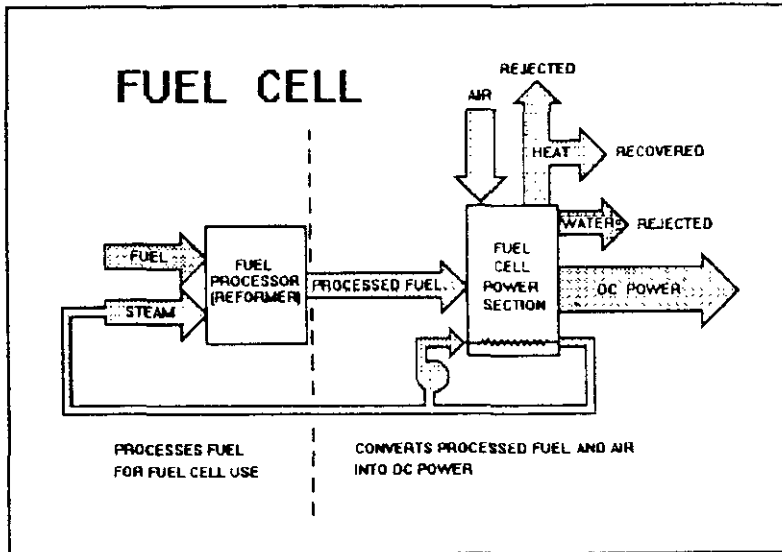
Hydrogen can be stored as a compressed gas, as a low-temperature liquid, as a hydrogen-toluene compound or in the form of *metal hydride*. The last of these is a compound that releases gaseous hydrogen when heated, and which can be recharged with hydrogen when depleted. The advantage of metal hydrides is that they are inert and non-hazardous, in contrast to hydrogen gas which is highly explosive. Compressed hydrogen tends to be extremely bulky, so most researchers favour cryogenic liquid storage.

Hydrogen has a calorific value of 120 megajoules per kilogram, compared with just 48 MJ/kg for petrol. But this high energy content is offset by its low density, and a liquid hydrogen tank requires more storage space than a conventional fuel tank.

A more efficient use of hydrogen gas can be made using fuel cells, which combine hydrogen and oxygen without undergoing a thermodynamic cycle. The efficiency of the process is thus approximately twice as great. Figure 5.3 is a schematic diagram of a fuel cell.

During 1991, fuel cell technology was claimed to have been significantly advanced by the invention of a new device called the Lasercell. This fuel cell can be run in reverse in order to generate hydrogen fuel. In practical terms, the cell can be connected to the electricity supply when the car is not in use, and the metal hydride tank replenished (Webb, 1991).

Figure 5.3 Schematic diagram of a typical fuel cell



Source: University of California, 1991.

As with electric vehicles, the level of CO₂ emissions from hydrogen-powered vehicles depends on the source of the fuel. Hydrogen can be produced electrolytically using nuclear or renewable energy, with negligible emissions of greenhouse gases. Fossil fuels can be ruled out as a source of electricity, because hydrogen can be produced *directly* from fossil fuels with a greater efficiency. Sperling and DeLuchi (1989) indicate that:

Fossil fuels would not be used as the source of electric power because it would be cheaper and more efficient and would generate less carbon dioxide to make the hydrogen directly from fossil fuels. Hence nonfossil feedstocks, such as solar, geothermal, wind, hydro, and nuclear energy would be used to generate electricity for the electrolysis process.

Emissions of CO₂ from vehicles using any form of fossil-based hydrogen are considerably greater than those from conventional petrol or diesel engines. If, however, hydrogen is produced electrolytically using non-fossil electricity, it is possible to eliminate completely greenhouse emissions from vehicles (ibid). The possible exception is NO_x, which is produced during the combustion process. However, emissions of this gas can be minimised using lean mixtures, as well as various methods of combustion cooling.

In summary, hydrogen gas has a considerable potential for reducing greenhouse emissions at a competitive cost, but this needs to be coupled with the use of non-fossil energy supplies. Fuel cells, if they become commercially feasible, will offer better energy efficiency than IC hydrogen engines. However, hydrogen storage can present problems, particularly in smaller vehicles.

5.4.6. Alcohol fuels

Alcohol fuels have been a popular solution to a number of transport problems, particularly those related to air quality and oil supply security (see 5.4.2 above). In practical terms, alcohol fuels for transport comprise methanol (CH_3OH) and ethanol ($\text{CH}_3\text{CH}_2\text{OH}$). Alcohol fuels fall into the category of either *synthetic fuels* (synfuels) or *biomass* fuels.

Synfuels are typically fuels that are manufactured using coal or oil shale as feedstocks. As well as synthetic alcohols there are synthetic natural gas and synthetic petroleum. The production process is energy-intensive, and is usually justified on the grounds of oil supply shortages.¹ Sperling and DeLuchi (1989) have outlined the disadvantages of synfuels compared with conventional motor fuels. One observation in particular is of relevance from a greenhouse perspective:

Possibly the most serious environmental impact is the large amount of carbon dioxide emitted by the use of coal and oil shale-based fuels. [These] produce about twice as much carbon dioxide as petroleum. If the scientific consensus on the seriousness of the greenhouse effect is translated into policy, coal and oil shale-derived fuels could be eliminated by this criterion alone.

Methanol can be manufactured from natural gas, but the reduction in greenhouse emissions compared with conventional petroleum fuel is very small; Sperling and DeLuchi (op. cit.) estimate that methanol based on natural gas could reduce emissions by just three per cent relative to an equivalent petrol-engined vehicle. It is unlikely that such a small benefit in terms of greenhouse emissions could ever justify a switch to this fuel. This is especially true at the moment, since improvements in vehicle fuel economy can offer greater reductions at a lower cost (see below).

The use of methanol is expected to increase in the USA (and in particular California) because of air quality concerns, and natural gas is favoured as a feedstock for the fuel because of its abundance at low cost. However, emissions of greenhouse gases are nevertheless lower when natural gas is used directly as a motor fuel than when it is first converted to methanol.

In summary, alcohols based on fossil fuel feedstocks have no part to play in providing a less carbon-intensive substitute for petroleum, and can be discarded as options for reducing emissions of CO_2 .

The other option for the manufacture of alcohols is biomass, or plant matter. The potential for reducing CO_2 emissions by switching to biofuels is considerable. Although CO_2 is produced when plant matter is combusted or otherwise oxidised, an equivalent volume of

CO₂ can be recovered from the atmosphere by replacing the harvested plant matter, which as part of its photosynthetic process absorbs this gas from the air. In principle, a biofuel plantation which grows as rapidly as vegetation is removed can have zero net emissions of CO₂. In practice, there would probably be a low net level of emissions from the fuel manufacturing process.

Two broad categories of feedstock are available for the production of alcohol biofuels. Firstly, crops and food wastes containing large amounts of starch and sugar, such as sugar cane and maize, may be fermented to produce ethanol. Secondly, a form of biomass that is cheaper and more abundant is *lignocellulosic* material, derived mainly from tree products. Cellulose can be either thermochemically processed to make methanol or hydrolysed to produce ethanol.

In summary, to be useful as part of a greenhouse strategy, ethanol and methanol must be derived from biomass. This is likely to consist of a combination of organic wastes and dedicated fuel crops. The principal limitation on the use of alcohols is the area of land available for growing energy crops.

Presently, throughout the EC, farmland is becoming redundant as a result of a community-wide rationalisation of agricultural output. Subsidies are paid to some farmers in Britain who leave parts of their land unused, under the 'set-aside' scheme.

Large areas of land would be suitable for growing energy crops. In addition to the 'set-aside' land, upland areas that are presently planted with coniferous trees might be replanted with fast-growing energy crops.

5.4.7. Natural oils

A number of plant species are available that produce oils similar in nature to diesel fuel. These include palm, coconut, sunflower, rape and soya. Some of these could be grown successfully in Britain's climate.

Soya oil has a calorific value of 37 MJ/kg, compared with 42 MJ/kg for diesel. However, its boiling point is considerably higher than diesel's, and it solidifies at a higher temperature, which implies difficulties with frozen fuel in cold weather. Furthermore, its viscosity is some 10 times greater than that of diesel. These problems typify those of other vegetable oils (Knight and Cooke, 1985).

However, the technical difficulties are not insuperable, and natural oils can offer a form of energy that produces virtually no greenhouse emissions. As with plant-based alcohols, there is land available in Britain and the rest of Europe for cultivating these crops. However, there would not be a sufficient supply of natural oils to supply all of Britain's needs.

5.4.8. Natural gas

Natural gas consists mainly of methane, and is found principally in gas wells such as those in the North Sea. It has a relatively low carbon content: for an equivalent energy content, natural gas has approximately 25 per cent less carbon than petrol, and emissions of CO₂ are correspondingly less.

Natural gas is used to propel approximately 0.25 per cent of vehicles in Europe, most of which are conversions of petrol-engined vehicles sold in Italy (Dallemagne, 1990). It is available for use in vehicles in the form of either compressed natural gas (CNG) or liquefied natural gas (LNG). CNG is the more popular option, as the production costs are lower than those for LNG. It is burned in a conventional IC engine, and most conventional petrol engines can be adapted to run on CNG.

Moderate reductions in CO₂ emissions can be achieved by switching to LNG or CNG vehicles. However, concerns have been raised over emissions of methane, itself a greenhouse gas, which is released from natural gas vehicles through fuel leakage. Chapter One shows that molecules of methane are some 25 times more powerful as radiative forcing agents than those of CO₂. It has even been suggested that emissions of methane could offset the savings in CO₂ resulting from the use of natural gas, and render the fuel worthless as a means of reducing greenhouse emissions. Mills et al (1991) describe the effect thus:

... if only CO₂ is counted, compressed natural gas (CNG) automobiles appear 'better' than gasoline-fuelled cars. However, total greenhouse gas emissions are in fact greater for CNG automobiles after including the CO₂ releases from fuel production and related methane and N₂O emissions.

It is likely that methane leakages would be smaller in purpose-built natural gas vehicles than in adapted petrol-engined vehicles. But the latter comprise the vast majority of natural gas-powered vehicles worldwide, and so in the short term the value of natural gas as part of a greenhouse strategy is subject to uncertainty.

Emissions of CO from natural gas engines can be reduced to very low levels, although the use of catalysts might be required in order to meet future requirements concerning NO_x emissions.

In the longer term, the supply of natural gas at competitive prices is subject to some doubt. The House of Lords (1991) estimates that known reserves of natural gas will be depleted within 60 years if present consumption rates continue. Natural gas cannot therefore be viewed as a long-term option for transport fuel.

A fuel closely resembling natural gas can be manufactured from biomass, such as wood chips, using a thermochemical gasification process. The gasifier uses heat to convert woody biomass into distillates, and may be carried aboard the vehicle. More commonly, gasifiers are used as stationary sources of power in remote areas. As with other biofuels, the net emissions of CO₂ from gasified biomass can in principle be reduced to zero, if the gasification process is powered by the energy that it releases.

The cost of retrofitting a vehicle to run on CNG is considerable. However, purpose-built CNG cars would be unlikely to cost much more than petrol-engined vehicles. Refuelling could take place using the public gas supply, subject to requirements concerning impurities in the fuel. A critical obstacle to the introduction of natural gas is the limited availability of the fuel, which requires vehicles to be able to run on petrol too. These dual-fuel designs fall well below the optimum efficiency of dedicated natural gas engines (Dallemaigne, 1990). Overall, natural gas appears to have little to offer as part of an overall greenhouse gas reduction strategy.

5.4.9. Liquid petroleum gas (LPG)

Liquid petroleum gas consists of propane (C₃H₈) and butane (C₄H₁₀), and is a by-product of the drilling and distillation of crude oil. Emissions of greenhouse gases are lower than those from conventional petrol engines, and LPG is classified as a 'clean' fuel under California's air quality programme. Conventional petrol engines can be made to run on LPG by an adjustment to the carburettor. Presently around 1.3 per cent of cars in Europe are powered by LPG.

Like natural gas, LPG has a lower calorific value than petrol. This means that a larger fuel tank is required in which to store the pressurised fuel, which may cause design problems in smaller vehicles. This is particularly the case if the vehicle is fitted with both petrol and LPG tanks. In addition, the efficient design of LPG engines is at present hampered by the need to run on both LPG and petrol.

Since LPG is a by-product of petroleum production, its supply depends on the production of conventional motor fuels. As part of a CO₂ reduction strategy, LPG could be useful, but not on a large scale.

5.4.10. Alternative heat engines

So far, the options for alternative combustion fuels have been viewed in the context of internal combustion (IC) engines. However, a variety of alternative engine types exist, which offer a potential for reducing CO₂ emissions. The three designs examined here are:

- ❑ Stirling engines;
- ❑ Gas turbines;
- ❑ Rankine engines.

All three of these alternative engines operate using continuous combustion, rather than the intermittent combustion of spark and diesel engines. The technical details and applicability of these technologies are discussed in full by the Department of Energy (1981).

Stirling engines operate by forcing a gas between hot and cold spaces, and using the expansive work to move a piston. The working fluid is enclosed in a sealed system, with combustion taking place externally. This means that a wide variety of fuels can be used, offering the potential for a broad range of biofuels in solid, liquid or gaseous state.

Most of the research relating to automotive Stirling engines has been applied to trucks, buses and large cars. The Department of Energy (op. cit.) points to the practical difficulties associated with Stirling engines, but concludes that the Stirling has an advantage 'in terms of noise, vibration, and possibly in emissions.' It also points to 'the long-term importance of fuel flexibility which is greater in the case of the Stirling than for any other heat engine which is a candidate for road vehicles.'

Gas turbines are a form of the *Brayton engine*, where the working fluid is exhausted after each cycle. Air is compressed and passed into the continuous combustion chamber where it is heated by the burning fuel. The hot gases then expand to ambient pressure, turning a turbine wheel, and are thence expelled to the atmosphere. Gas turbines are associated with a degree of fuel flexibility as well as a long service life. Engine efficiency is optimised at maximum load, which is associated with very high rotational speeds. For this reason, Dallemagne (1990) suggests that the most suitable application might be in a hybrid vehicle, in which the turbine is operated occasionally for the purposes of recharging the batteries or supplying additional motive power to the vehicle.

The application of gas turbines is technically simpler and more energy-efficient in larger vehicles such as trucks and buses than it is in typically-sized cars.

Rankine engines are best known in the form of the steam engine, which was used in commercial railways as recently as the 1960s. The working fluid, usually water, alternates between liquid and gaseous states. Steam cars were in use from around 1900, but were

superceded by internal combustion engines whose efficiency and power-to-weight ratio were higher.

The efficiency of Rankine engines is poor compared with other heat engines, but they can be operated on a broad range of fuels. Overall, the Stirling engine is more attractive, and ‘... it is widely accepted that the Rankine engine is not a serious prospect for road vehicles’ (Department of Energy, op. cit.).

It appears unlikely that alternative heat engines will offer significant energy savings over, for example, advanced diesel engines. However, their value in reducing CO₂ emissions lies in their fuel flexibility, which allows recycled biomass fuels to be used. On this basis it would appear that the greatest potential for reducing CO₂ emissions from heat engines lies in the Stirling engine.

In addition to the three alternatives considered above, there is also some potential for novel configurations of the conventional petrol engine. *Two-stroke engines* can now offer higher levels of fuel economy than conventional four-strokes, by virtue of the direct injection of fuel into the combustion chamber. *Catalytic ignition* engines make use of a platinum catalyst to ignite the fuel/air mixture, rather than using spark or compression ignition. NO_x emissions tend to be less, by virtue of the lower combustion temperature. This type of engine is at an early stage of development.

5.4.11. Prospects for alternative rail transport fuels

As a growing proportion of rail operations are powered by electricity, the option of alternative fuels in railways consists largely of alternative means of generating electricity. The prospects for alternative sources of electricity are outlined above in the consideration of electric road vehicles.

Presently electric rail vehicles draw their power from the regional electricity companies, and the electricity is predominantly coal-based. Alternative fuels thus imply changes in the electricity supply industry, which has the option of switching some of its capacity to fuels that are less carbon-intensive. The development of renewable energy sources is beyond the scope of this study, but it is noted that a switch away from coal and towards non-fossil energy sources would have the effect of reducing CO₂ emissions in the transport sector.

The Electricity Act 1989 made it possible for private investors to generate electricity and sell it to the regional electricity companies. In principle it would be possible for a transport operator such as British Rail to develop its own sources of renewable energy, such as wind turbines situated on sidings and embankments. It is unlikely that such a venture will be possible in the near future, unless it were cheaper than buying electricity from regional

supply companies. However, such an option would be viable as part of a transport investment package that takes into account CO₂ emissions.

Alternative fuels may also be developed for non-electric rail operations. A number of fuels are available as a substitute for diesel in locomotives, including natural gas, LPG, hydrogen and alcohols. The technical difficulties associated with developing these fuels for rail use would be less than for road transport, since there is less constraint on space in locomotives than there is in road vehicles. In addition, the refuelling regime would present fewer problems, since rail journeys tend to be repetitive and highly scheduled.

At present there is no indication that alternative fuels will be developed for rail use, and the reasons for this include:

- ❑ The capital required for an investment in alternative fuels is not justifiable alongside more pressing needs such as updating stock and improving safety;
- ❑ The main motivation for saving energy in rail operations is economic, and the most cost-effective reductions in specific energy consumption can be achieved through technical refinements in materials, aerodynamics and so on, rather than by switching to new fuels;
- ❑ From the perspective of national CO₂ emissions, rail travel represents around three per cent of the total output. A reduction in the carbon-intensity of rail transport will have a minor effect on overall emissions, even if the volume of rail travel increases substantially.

The most promising prospects for less carbon-intensive rail fuels would appear to lie within the electricity supply industry. The current rail stock consists of a mixture of diesel and electric vehicles, and at present there is little reduction in greenhouse emissions associated with a switch from diesel to electric traction. If the electricity supply industry were to become substantially less carbon-intensive, electrification would offer significant reductions in emissions of CO₂.

5.4.12. Prospects for alternative air transport fuels

In principle, aircraft can be operated on a variety of fuels, and a number of them have been used successfully in prototypes. However, there are technical difficulties associated with alternative aviation fuels, and these impose severe limits on the commercial viability of these fuels (Momeny, 1991).

As with road transport, alternative fuels are only considered useful in this study if the overall level of CO₂ and other greenhouse emissions is lower than that from conventional-fuelled vehicles. On this basis, the options available for aircraft are

- Hydrogen, produced from nuclear or renewable sources of energy;
- Alcohols, derived from renewable biomass;
- Natural gas.

One of the most serious obstacles to alternative aviation fuels is the problem of fuel storage. Hydrogen fuel has a high energy content per unit mass, but a low energy content per unit volume. Hydrogen would require over four times the volume of an equivalent quantity of conventional jet fuel. Methanol has both a large mass and a large volume for an equivalent quantity of energy. Given that commercial aircraft already carry very large quantities of fuel at take-off, it can be seen that any additional demands on storage space are difficult to satisfy. As is the case with road transport, natural gas is of questionable benefit in reducing greenhouse emissions, because significant amounts of methane are released to the atmosphere during processing and refuelling.

The technical difficulties associated with alternative aviation fuels are formidable, particularly for the options that are less carbon-intensive than conventional jet fuel. The development of alternative fuels will be more straightforward in land-borne transport systems, which account for the majority of travel-related emissions. Momethy (op. cit.) examines in detail the technical challenges of alternative aircraft fuels, and concludes that 'efficiency improvement is the technically and economically best way to control the production of CO₂.'

5.4.13. Alternative fuels: options for reducing CO₂ emissions

A study undertaken in the USA (Sperling and DeLuchi, 1989) compares the greenhouse emissions of alternative-fuelled vehicles with those of conventional vehicles, using various assumptions about the source of the energy. The analysis takes into account not only CO₂ but also methane (CH₄) and nitrous oxide (N₂O). The results are reproduced in Table 5.4, and can be used to ascertain which alternative fuel options are of use as part of a strategy for reducing greenhouse emissions from personal travel.

Table 5.4 Relative greenhouse emissions per kilometre of different energy sources relative to petrol engines in the USA

<u>Fuel feedstock</u>	<u>Per cent change</u>
Electric vehicles, nonfossil electricity	-100
Hydrogen from nonfossil electrolysis	-100
Natural gas/methanol from biomass	-100
CNG from natural gas	-19
Electric vehicles with natural gas plants	-16
LNG from natural gas	-15
Methanol from natural gas	-3
Electric vehicles from current power mix	-1
Petrol and diesel from crude oil	0
Electric vehicles with new coal plant	+26
Metal hydride from coal	+100
Liquid hydrogen from coal	+143

Source: Sperling and DeLuchi, 1989.

A vital caveat accompanying results such as these is that they do not always compare like with like. The performance of alternative-fuelled vehicles (in terms of power and body weight) is often considerably less than that of the conventional IC-engined vehicle against which they are being compared. For example, the General Motors Impact electric car, described earlier, is built from lightweight materials and contains a number of other energy-saving features such as high-pressure tyres and advanced aerodynamics. If these features were to be applied to a small, low-powered IC-engined vehicle, the resulting fuel economy would be extremely high. Improving the fuel economy of the IC-engined fleet, using technologies such as these, would reduce the value of alternative fuels.

In Britain, where cars are on average more economical than in the USA, the benefits of alternative fuels are therefore less pronounced than Table 5.4 indicates. The assessment of alternative fuels made by Sperling and DeLuchi (op. cit.) assumes the current level of fuel economy in the USA, and not the maximum that is technically feasible.

Based on the above analysis, the following options for alternative surface transport fuels may be considered viable as part of a strategy for reducing CO₂ emissions:

- ❑ Electricity, based on natural gas, nuclear or renewable energy;
- ❑ Hydrogen (oxidised either in internal combustion engines or in fuel cells), with the gas produced electrolytically. As with electric vehicles, the electricity for this process must be based on natural gas, nuclear or renewable energy;
- ❑ Alcohols, oils and gases derived from biomass (fuel crops and organic waste);

Given that the majority of CO₂ from personal travel is produced by private cars, an investment in alternative fuels will yield greatest benefit if applied to this sector. In many ways, however, the technical obstacles to alternative fuels are much less severe in buses, coaches and trains than they are in private cars, for reasons associated with vehicle size, predictability of usage, and refuelling (cars have many more refuelling points than other modes of transport). It may therefore be feasible for these modes to adopt alternative fuels too. The technical difficulties associated with alternative aviation fuels are considerable, and will rule out their use in the foreseeable future.

5.4.14. Relative costs of alternative energy sources

Dallemagne (1990) has performed a costing exercise for all of the alternative fuel options available, based on the year 2010 and assuming all the vehicle's lifetime costs. His estimates are reproduced in Table 5.5.

Table 5.5 Cost estimates for alternative fuel options in 2010

<u>Fuel option</u>	<u>Total cost (ECU₁₉₉₀ per 100km)</u>
Petrol	15.9 - 21.0
Diesel	12.3 - 15.8
Sodium-sulphur battery	9.9 - 20.2
Liquefied solar hydrogen	16.5 - 30.9
Metal hydride (solar)	16.1 - 27.9
Methanol	14.3 - 17.6
Compressed natural gas	11.7 - 16.8

Source: Dallemagne, 1990.

These figures suggest that none of the alternative fuel options considered by this study is likely to cost much more than petrol by the year 2010. Over the timescale of this study, all of the options identified here are considered to be economically viable, though the availability of energy supplies may be limited.

5.4.15. The role of regulations in promoting alternative fuels

The development of alternative fuels in the USA has been stimulated by government regulations. A number of alternative fuel programmes have been mandated by the federal government's 1990 Clean Air Act Amendments, whilst California's standards require a proportion of vehicles to be 'low-emissions vehicles' by 2000.

The current competition between manufacturers to develop a practical electric vehicle would have been unlikely to take root in a 'business-as-usual' market for cars. The cost of investing in new technology, together with the paucity of demand for alternative fuels, would not have allowed car manufacturers to diversify into new forms of propulsion.

The same effect can be found in Europe. Before EC legislation was passed requiring cars to be fitted with catalytic converters, car manufacturers in the UK were reluctant to cater for the new technology. The prospects for alternative fuels can be viewed from a similar perspective: government mandates aimed at promoting alternatives to petroleum would be likely to stimulate a market for alternative-fuelled vehicles. Until then, most of the alternative fuel options will continue to be subject to a closed loop: the fuels are not available to the public, so interest is lacking; but the fuels will only become available when demand for the fuels becomes significant. Government regulations have been shown to be effective as a means of breaking out of this loop.

5.4.16. The role of market mechanisms in promoting alternative fuels

At present, alternative fuels cannot in general be justified on economic grounds. Cheap petroleum and an absence of regulation mean that car manufacturers have little incentive to develop non-petroleum vehicles.

However, market forces may be used to promote alternative fuels if appropriate intervention is used. A carbon tax, as described above, would effectively raise the price of fossil-based fuels and make alternative energy sources more attractive to consumers. Crucially, *it would also exclude the use of alternative fuels that have no value in reducing CO₂ emissions*, such as hydrogen made from coal.

Alternatively, the existing taxation system might be adjusted to discriminate in favour of 'cleaner' vehicles. Reduced rates of taxation for particular vehicle types or fuels could be effective in promoting sales of less carbon-intensive products.¹

Such a programme was established in Brazil in 1975 as part of a drive to promote ethanol as a motor fuel. The national government intervened in several sectors of the economy, providing incentives for research and investment programmes, giving price guarantees to producers, and increasing taxes on motorists. Under circumstances of 'business as usual', the development of alcohol fuel on this scale could not have been economically justified (Weiss, 1990).

Potter (1992a) suggests that fiscal measures could be used to promote alternative fuels in addition to fuel economy improvements, but stresses the importance of a 'system-wide' assessment of emissions. Fiscal incentives should be based on the whole-cycle level of emissions, rather than simply pollution from the tailpipe.

A system of tradeable permits could also be used to encourage car manufacturers to sell alternative-fuelled vehicles. Such a scheme is built into the Californian programme of alternative fuels development:

From 1998, any company that wants to sell more than 35,000 cars in the state must make sure 2 per cent of them are "zero-emission vehicles", emitting no pollutants at all. That figure will rise to 10 per cent by 2003....

Companies are not forced to develop a commercially viable zero-emission car. If they think that is impossible, they have a simple option: to sell their own, or someone else's, electric cars at a subsidised price low enough to attract buyers - and to cover the cost of doing so by raising prices on their petrol cars.

There is one further twist. If a company manages to develop an electric car that accounts for more than 2 per cent of its sales, the firm can claim a credit for every extra one it sells. Those credits can then be sold on the open market to other companies to fulfil their quotas.

(Jackson and Schoon, 1991)

¹ At present electric vehicles are exempt from Vehicle Excise duty (VED) in the UK. However, this tax constitutes a small fraction of motoring costs (£100 per year for private cars), and the incentive is not sufficiently large to stimulate a market for electric vehicles.

5.4.17. Summary: the scope of technological solutions

The above sections have examined technological changes that may be made in the vehicle stock. Measures to encourage fuel economy in new vehicles have a considerable potential for reducing CO₂ emissions from personal travel. In addition, alternative fuels can also play a part, although the technology needs further development. Attention must be given to the primary source of energy when assessing alternative fuels as policy options. For example, many of the possible solutions can only be of use if there is a substantial change in the way electricity is generated in Britain.

The technological solutions outlined above are unlikely to be adopted in a business-as-usual scenario. Whilst there is a degree of environmental benevolence in the market for cars, there are no indications that this will be sufficient to bring about major changes in the nature of private vehicles. Instead, regulations and market-based instruments must be used to stimulate interest in these technologies. In the passenger transport sector, market-based instruments tend to be more appropriate since they do not impinge upon freedom of choice, and tend to offer consumers a variety of possible actions.

This following chapter will evaluate the potential of technological solutions (Approach A) in controlling CO₂ emissions. Beyond technological measures lie more radical policies, aimed at modifying the nature of travel demand itself (Approach B). If necessary, these would need to be deployed in conjunction with Approach A. The next section discusses the policy options available for influencing the volume and structure of personal travel.

5.5. Measures to promote modified travel patterns

As with the technological options contained in Approach A, measures for altering the nature and volume of travel demand consist of regulations, market-based instruments and investment. All three can influence personal travel decisions.

Figure 2.7 compared the primary energy consumption of various travel modes in Britain, and showed that substantial variations exist between different forms of transport. Emissions of CO₂ are directly proportional to energy consumption, given a particular source of energy. If a strategy of technological solutions were insufficient to hold down CO₂ emissions to the desired level, it would be necessary to stimulate some transfer from car travel to more energy-efficient modes such as bus and rail, or alternatively to the non-motorised modes of walking and cycling.

Furthermore, such modal changes are closely coupled with reductions in overall travel volume, since travel by car tends to be associated with longer, and often more frequent, journeys rather than simple replication of journeys by other modes.

Below are outlined policies that could be deployed in order to modify current patterns of travel demand. They address both modal transfer and reductions in travel volume, which are intimately related. As before, the proposals are ordered with reference to the three forms of policy measure introduced earlier in the chapter, namely regulations, market-based incentives and public investment.

5.5.1. The role of regulations in altering travel demand

Personal travel should be viewed as a means of gaining access to people and facilities, rather than an activity in itself. On this basis, Goodwin et al (1991) distinguish transport from other activities:

[Transport] is unlike many other fundamental human activities in that in most cases movement is a means to an end, not an end in itself. There are exceptions, such as a pleasure cruise, or walking the dog, but for most day to day trips we do not really want to travel at all - we want to participate in some activity in a different place and transport is simply something we have to do to enable this.

There is considerable potential for reducing journey lengths by bringing journey 'ends' closer together. Examples include locating businesses, shops and schools in closer proximity to the residential areas that they serve.

PLANNING REGULATIONS

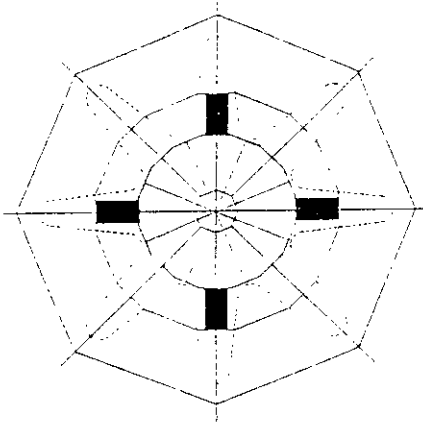
The growth in personal mobility resulting from rising car ownership has led to an increasingly dispersed pattern of land-use. The sustained movement of the population out of traditional centres and into suburbs and new towns has been described in Chapter Two. Goodwin et al (op. cit.) have examined the trends that have led to the decentralisation of urban areas. Car ownership began to rise in the 1930s, encouraging 'ribbon' developments between urban centres. More recently, relaxed planning regulations have allowed the retail and industrial sectors to relocate alongside major routes, and multiple car ownership has allowed some households to live in remote areas and to commute long distances to work. Planning regulations have required a minimum ratio of parking spaces to employees, even in central London.

In accordance with these trends, many building developments have been constructed with car travel in mind, and as such have led to the partial demise of public transport services, which are often unable to operate viable services in a highly dispersed settlement pattern. Manifestations of this effect include the numerous out-of-town retailing centres and housing developments to be found on the outskirts of major towns and cities.

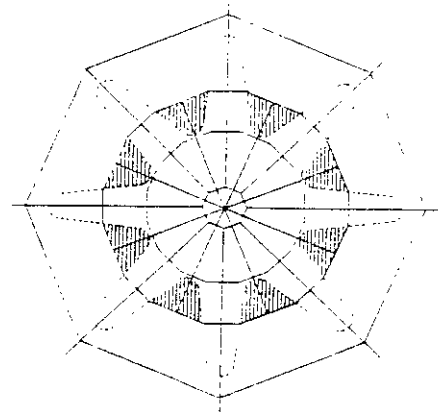
Chapter Two showed that the number of journeys per person in Britain has shown little change since 1975, or between different settlement densities. Owens (1986) suggests that a reduction in overall travel would be brought about principally by the introduction of shorter journeys, rather than by reducing the number of trips. This fits well with the need for equitable solutions to transport problems. A scheme whereby journeys were 'rationed' would raise justifiable objections on the grounds of freedom of access. Policies to maintain access while reducing travel need would address this acceptability problem.

Steadman and Barrett (1991) have investigated the effect of different land-use policies on transport-related CO₂ emissions. Using a computer model, five different configurations are compared against a 'typical' town of population 72,000. It is shown that reductions in energy demand and CO₂ emissions can be achieved by switching to a centralised structure, or alternatively to one consisting of a number of 'village' centres. These are reproduced in Figure 5.4.

Figure 5.4 Energy-saving urban forms



(a) development of existing sub-centres, with improved radial and orbital road links



(b) high-density peripheral development, with improved radial and orbital road links

Source: Steadman and Barrett, 1991.

The authors conclude that

... 10-15 per cent savings in fuel use for passenger transport can be achieved through land use changes at the city-regional scale over a 25 year period. The effects are produced by

centralising a part of the population which was previously dispersed, into the central city or into villages; and so shortening average trip lengths.

Newman and Kenworthy (1990) have conducted a survey of cities worldwide and demonstrated a relationship between urban density and travel-related energy consumption. The broad conclusion to be drawn is that higher-density urban layouts tend to be associated with lower levels of energy consumption per capita.

However, there are some important exceptions to this observation. Hall (1991) holds the view that urban structure, rather than density, is the key determinant of energy consumption. For example, "... the efficiency of a city like Stockholm is due not to its relatively high overall density but to its polynuclear structure." Furthermore, there are certain low-density options that would also have relatively low levels of energy use.

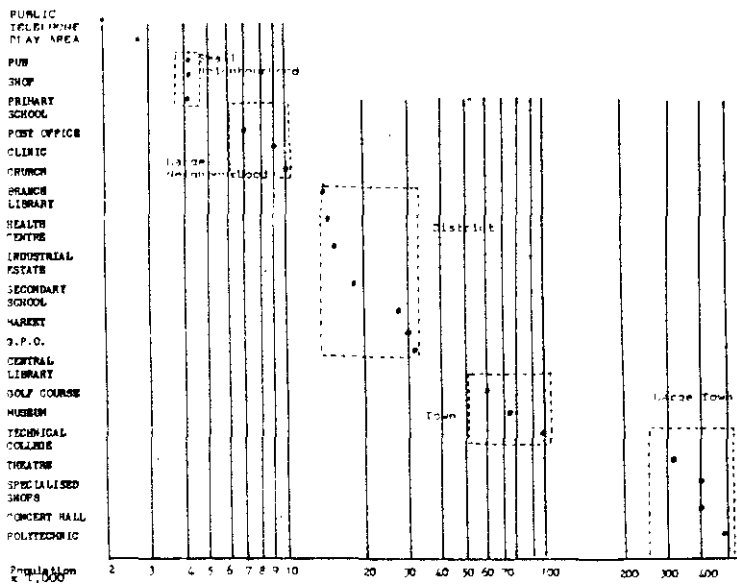
Nevertheless, it is not disputed that there is a widespread correlation between urban density and mobility. Potter and Hughes (1990) have used National Travel Survey data to demonstrate a relationship between density and walking distances to local facilities, as well as modal distribution. It is shown that there are critical density thresholds at 15-20 persons per hectare (pph) and 45-50 pph. Above the former threshold, walk trips rise to approximately 35 per cent of all trips, whilst above the latter walking rises to 40 per cent of trips. Similar thresholds are identified for bus, rail and car use.

Potter (1976) has related the modal distribution of trips to population catchments, showing that for walk and bus trips there are significant catchment thresholds at 10,000 people (neighbourhood), 25,000 (district), 70,000 (town) and 300,000 (city). Urban forms that provide such catchments allow public transport to operate efficiently, as well as reducing the need for motorised travel. The small towns of Redditch and Runcorn, with populations of approximately 60,000, are shown to support high levels of bus provision without resorting to high densities. A broad correlation between catchment population and accessible facilities is illustrated in Figure 5.5.

In summary, an empirical relationship can be demonstrated between urban density and travel-related energy use. However, policy measures for reducing energy demand do not necessarily depend on increased densities. A variety of structures are available that combine relatively low densities with high levels of public and non-motorised travel. Potter (1991b) summarises the position thus:

Although very high densities are least car dependent, medium density settlements of individual houses with gardens can be compatible with reduced car use, particularly if combined with careful land-use planning designed to reduce travel need.

Figure 5.5 Facilities supported by different populations



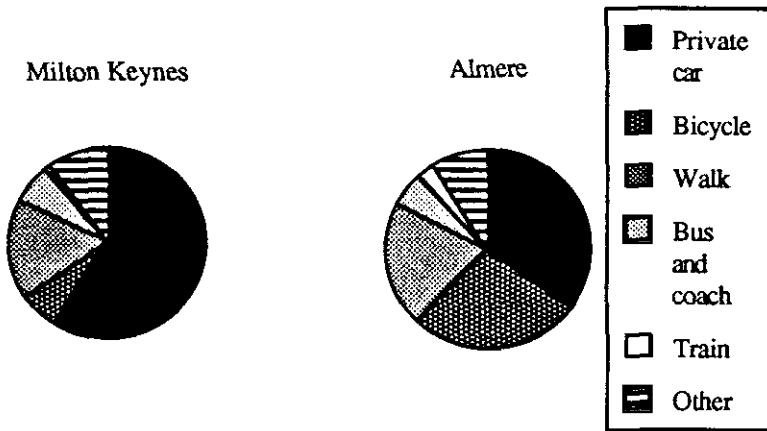
Source: Potter, 1976.

In Britain, four per cent of journeys are by bicycle. In Denmark, the equivalent figure is 18 per cent, whilst in the Netherlands it is 29 per cent (Royal Town Planning Institute, 1991). A report by TEST (1991) has compared in detail the travel behaviour of residents in Milton Keynes with that of people living in Almere, a comparable new town in the Netherlands. Figure 5.5 compares the modal distribution of travel in the two towns, and shows that car travel accounts for the majority of trips in Milton Keynes. Travel by bicycle, on the other hand, is far more popular in Almere than in Milton Keynes. Figures such as these give an indication of the change in travel patterns that might be achieved through a gradual transition to a more access-based approach to town planning. TEST concludes that ‘... the difference in modal split can be attributed to the dissimilar land use structures, travel facilities and culture of the two cities.’

As part of a package of measures, therefore, land-use planning to reduce the need for travel, together with an improved availability of public and non-motorised travel facilities, can bring about a substantial change in modal distribution, as well as a reduction in overall travel.

Government regulations could be introduced requiring businesses, retailers, public services and so on to choose locations that can be easily reached without the use of a car. For example, planning permission for retail outlets might be easier to obtain for city-centre locations than for out-of-town sites.

Figure 5.6 Modal distribution of trips in Milton Keynes and Almere



Source: TEST, 1991.

By encouraging urban development to take the form of energy-saving designs such as those proposed by Steadman and Barrett, national government could make a significant long-term contribution towards reducing energy consumption and greenhouse emissions in personal travel.

Land-use policy alone does not influence travel volume. Steadman and Barrett (op. cit.) point out that

Time budget studies show that people with higher incomes and better access to cars spend roughly the same total amount of time on travel per week as poorer people without cars. Thus people do not spend money to save time on travel overall; rather they devote the same time to travelling further by faster modes. All this indicates that a reduction in car travel requires behavioural and attitudinal changes, as well as land use policies.

Land-use policies must therefore be used in conjunction with measures aimed at influencing individual travel choices, in order to realise their potential for reducing CO₂ emissions.

CAR PARKING REGULATIONS

An important element of a policy for reducing the use of cars in urban areas is the regulation of *parking* provision. The availability of car parking facilities in urban centres is a key determinant of the amount of traffic entering the centre. Whitelegg (1990b) has described the change in attitudes that has taken place in a number of German cities, as witnessed by new

approaches to urban transport provision. Among the measures that have gained popularity is the 'reduction and eventual elimination of short-term car parking in cities'.

Alongside reductions in the availability of car parking space in cities, it is widely recommended that *park and ride* schemes be introduced (see, for example, the Royal Town Planning Institute, 1991). These involve the provision of car parking space outside the urban centre, and a frequent, cheap bus service to carry visitors into the centre. But in terms of CO₂ production, this only affects part of a journey. Closely coupled with parking regulations is the possibility of introducing traffic calming and other urban traffic measures (see below).

EMPLOYER-BASED TRAVEL PROGRAMMES

A further means of influencing travel behaviour through legislation involves employer-based schemes mandated by national or local government. Work-related travel accounts for 27 per cent of all car trips in Britain (Department of Transport, 1988). Policies aimed at influencing the use of cars for work travel therefore have considerable potential for reducing fuel consumption and greenhouse emissions.

Air pollution and, to a lesser extent, traffic congestion have reached crisis levels in several areas of the USA. In recent years, policymakers in North America have begun to look beyond automotive technology as a solution to environmental problems, and to consider the potential of 'transportation demand management' (TDM). Several pieces of legislation have been passed with the aim of reducing car mileage through increased load factors, modal transfer, park-and-ride schemes and so on. These include:

- ❑ The federal Clean Air Act Amendments (CAAA) of 1990, which require several states to implement schemes whereby employers with 100 or more staff are required to increase vehicle occupancy by at least 25 per cent for journeys to work;
- ❑ The California Clean Air Act of 1988, which requires average car occupancy to be raised to 1.5 by 1999, and aims to establish a cost-effective list of priorities for air pollution control measures;
- ❑ The Congestion Management Program, which requires local governments to assess the transport implications of new developments, and if necessary take action to reduce traffic levels (fees, park-and-ride, public transport provision and so on);
- ❑ The South Coast Air Quality Management District (SCAQMD) Regulation XV, aimed at reducing the number of vehicle miles in the morning peak

period: employers of more than 100 people must submit a plan for reducing single-occupant car travel in commuting trips.

A survey known as *State of the Commute* has monitored commuting patterns in several areas of California since 1989, and found a general increase in car pooling, van pooling and travel by non-motorised modes. In response to the legislation, a large number of companies have established pilot schemes with positive results (Collier, 1991).

TELECOMMUTING

The SCAQMD Regulation XV has prompted renewed interest in the practice of *telecommuting*, or working from home using an electronic interface. A number of employers have introduced telecommuting schemes in order to reduce the number of trips undertaken by certain employees.

A survey of telecommuters by Pendyala et al (1991) suggests that people who work from home alter their travel behaviour for a variety of journey purposes in addition to their work trips. The average trip length of telecommuters for non-work purposes was found to be significantly shorter than that of non-telecommuters, even on days when the normal journey to work was undertaken.

A programme of regulations in Britain aimed at stimulating employer-based travel schemes would be likely to have positive results in terms of reducing car usage for work purposes. At the moment there are a number of incentives for commuters to travel by car, such as the company car subsidy and the provision of free fuel and parking. It would not therefore be sensible to embark upon trip reduction strategies, such as those described above, until the current fiscal arrangements for commuters had been reassessed with environmental goals in mind.

5.5.2. The role of market-based instruments in altering travel demand

TRANSPORT TAXES

The taxation of transport has a significant effect on travel volume and modal choice. In particular, the subsidisation of company motoring by the government tends to encourage the use of cars, partly by discouraging the use of other modes and partly by increasing the overall level of travel (see 3.2.5). In most cases, company motorists receive some subsidy for private and commuting journeys as well as for business travel. By rationalising the taxation of company motoring, the subsidisation of private travel could be eliminated.

A number of the fiscal measures for the promotion of fuel economy that were discussed in 5.3.2 would also be likely to affect modal choice. For example, by relating taxation to car use rather than ownership, the marginal cost of using a car would increase, leading to a degree of modal transfer.

FUEL PRICING

Earlier in this chapter, *fuel pricing* was proposed as a means of promoting fuel economy in new cars. It can also be used as a market-based instrument for reducing car usage. Conventional wisdom suggests that traffic levels will show a short-term decline as a result of an increase in fuel price, but that the longer-term response will be less marked as motorists change to more economical cars. Although fuel pricing has a positive influence on fuel consumption, the benefit is principally through improvements in fuel economy.

Dix and Goodwin (1982) are doubtful about the benefit of fuel pricing as a policy measure for reducing travel demand:

In the long run, petrol prices will have a substantial effect on energy use by cars, but a smaller effect on traffic levels.... This means that petrol pricing should be viewed as being a *more* effective instrument for achieving energy conservation, and as *less* effective for controlling congestion, than has often been thought....

The review of elasticities undertaken by Dix and Goodwin supports the view that travel demand is not very responsive to increases in fuel price. In the face of rising fuel prices, car users tend to switch to a more economical car in order to maintain their existing level of mobility. Fuel pricing should not, therefore, be regarded as an ideal policy for influencing the demand for car travel.

Scale charges on fuel for company cars are currently charged as a 'flat rate' per car. This means that there is an incentive to consume the amount of fuel for which the driver is being charged. Any fuel consumed above this limit is not taxed at all. Potter (1992a) recommends that this method of taxation be redesigned so as to reflect the volume of fuel consumed.

The diminished volume of travel by company cars would be brought about through modal transfers, reductions in the average length of car trips, and the elimination of marginal additional trips.

COMMERCIAL TAXES

An indirect form of taxation on mobility takes the form of business taxes that are related to the accessibility of a firm's premises. The use of taxation to encourage businesses to locate their activities in places accessible by fuel-efficient and non-motorised modes would have a substantial, though gradual, effect on land-use patterns. Historically, unrestricted development has stimulated the development of out-of-town or 'green field' sites by commercial interests. In future, businesses could be encouraged to select more accessible locations through the use of an access-weighted version of taxes such as local business tax and the unified business rate. Rebates could be offered to companies that locate in accessible areas, in the same way that Enterprise Zones were established with rebates in the 1980s.

Changes in the location of businesses have a strong effect on the demand for travel, since a large proportion of personal mileage is involved in journeys to and from work. Moving to more accessible locations not only reduces the travel demand of employees; customers too can reduce their travel demand, as the services provided by the business are available closer to home.

There are caveats involved when advocating a move to more centralised patterns of development. The inverse relationship between density and energy consumption does not always hold. London, for example, comprises a massive employment centre surrounded by an extensive region from which workers commute, often over long distances. Banister and Banister (1991) have shown that the largest amount of travel among individuals in England and Wales occurs in a large ring in south-east England, centred on London. Small towns and semi-rural developments are often associated with relatively large travel distances. But in general, development in urban areas leads to less travel than an equivalent development on an out-of-town site.

Relocation also has implications for modal transfer. A move away from out-of-town sites and towards more central locations would allow many car users to switch to public and non-motorised modes of transport, which were not formerly available to them.

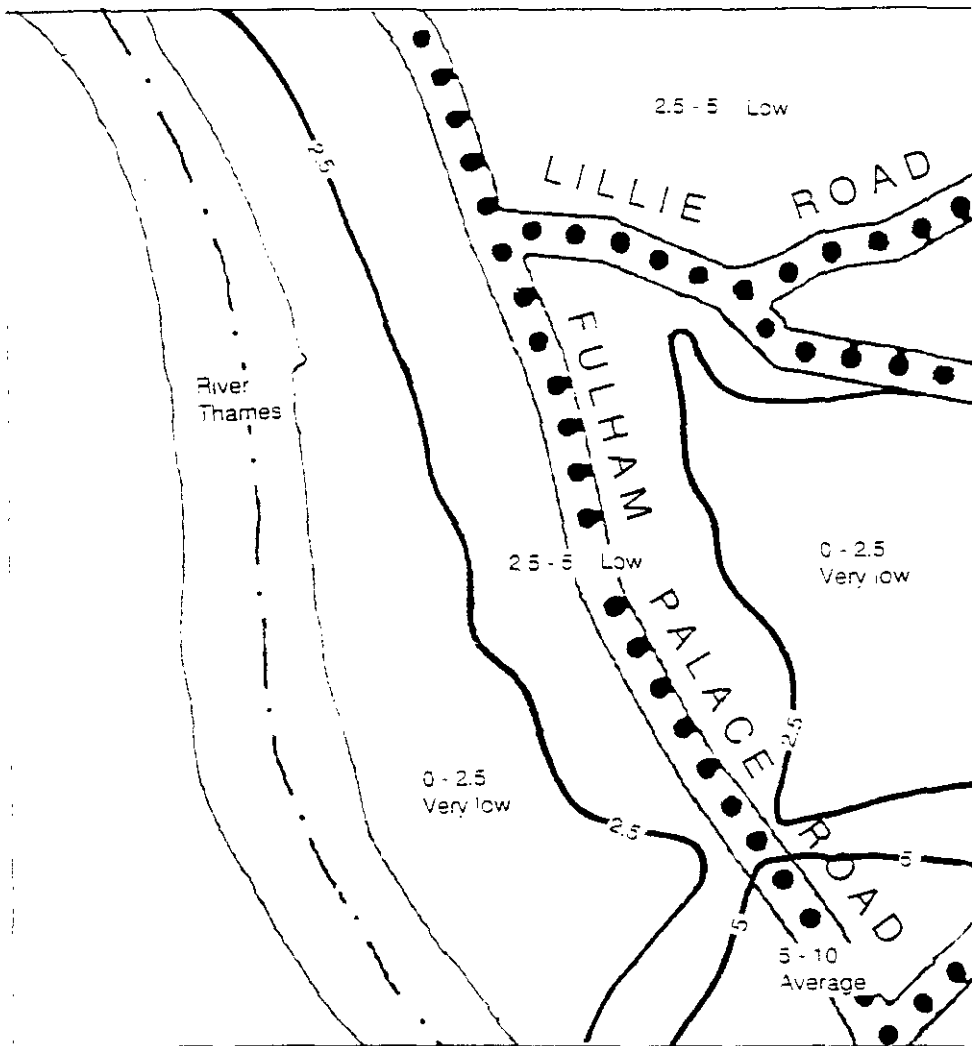
The Metropolitan Transport Research Unit (1990) has proposed a method of measuring accessibility, and produced 'accessibility maps' for particular urban areas. Figure 5.7 is a public transport accessibility map covering an area of Chelsea, based on a measure of accessibility that incorporates, among other things, walking times to the nearest transport service. The map indicates by means of 'accessibility contours' the availability of public transport services to residents of a particular area.

A similar definition of 'accessibility' might be used as the basis of a local tax on businesses, levied in proportion to their relative accessibility to customers and employees. The scheme might be extended to include employer-based travel programmes, outlined earlier in the

chapter: companies that took steps to reduce the volume of car travel undertaken by their employees might also be entitled to reduced rates of taxation.

The precise use of such measures as these remains speculative, and further research would have to be undertaken in order to ensure the effective use of measures to promote access by reducing the need to travel. It is, however, an important area for long-term policy development.

Figure 5.7 Public transport accessibility map for part of south-west London



ACCESSIBILITY RATING	
0 - 2.5	Very low Accessibility
2.5 - 5	Low Accessibility
3 - 10	Average Accessibility
10 - 15	Good Accessibility
15 - 20	Very good Accessibility

Borough Boundary	— . —
Contour Line	— — —
Bus Route	— ● — ● — ● — ● — ● —

To Putney Bridge

Source: Metropolitan Transport Research Unit, 1990.

CAR PARKING PROVISION

The level of car usage in urban areas is closely related to the provision of parking in the urban centre. Whitelegg (1990a) suggests that car parking spaces be allocated a 'rental' charge in order to promote the use of other travel modes for journeys into cities. He takes the view that charges should be set in a 'target-led' manner, rather than as the result of an abstract consideration of costs and benefits. 'Car parking in cities should be charged at whatever rate reduces its severity in a direct relationship with public transport charges and measures to improve the attractiveness of public transport.' (ibid.)

The provision of parking space can also be viewed in the context of company taxation. Since 1988, car parking provision has been exempt from personal taxation. Potter (1992a) suggests that there is scope for local taxes as well as Corporation Tax to reflect the environmental implications of urban parking provision.

ROAD PRICING AND AREA LICENSING

Another market-based option for reducing the demand for car travel is *road pricing*. One form of this is *area licensing*, whereby drivers are charged for entering a certain area (usually congested), often depending on the time of day. It has been widely advocated as a means of reducing urban traffic congestion, although there are other benefits including improved air quality and an enhanced urban environment.

Area licensing programmes introduced overseas have demonstrated significant benefits. Accompanied by improvements in the quality and capacity of alternative modes, area licensing can substantially reduce the number of cars driving into and around urban areas. A large proportion of the journeys affected are daily commuting trips.

A common criticism of area licensing and other road-pricing schemes is that they may simply rearrange the existing distribution of car trips (for example by promoting off-peak commuting) without affecting the overall modal distribution. Whitelegg (1991) outlines the arguments against road pricing as a means of reducing car use in urban areas:

Road pricing is not likely to be particularly effective in reducing the demand for car trips, cleaning up the environment or making cities better places in which to live. It will ration car-based access to congested areas by ability to pay and redistribute a proportion of trips in space and time with adverse consequences for local residents who may find themselves targets of a new generation of rat runs. This will not help to meet the urgent need for a cleaner environment, nor will it promote more walking and cycling....

However, the likelihood of failure can be reduced if pricing is introduced in conjunction with measures aimed at promoting the use of alternative modes, such as investment in and subsidisation of bus and rail services.

Area licensing may be linked to measures to promote car-sharing. Increased load factors can themselves reduce car traffic, so an incentive to share cars will have a beneficial effect on CO₂ emissions. Privileges such as reduced charges and car-pool lanes may be made available for high-occupancy vehicles. Special car-pool lanes for high-occupancy vehicles have been in operation in a number of American cities for many years.

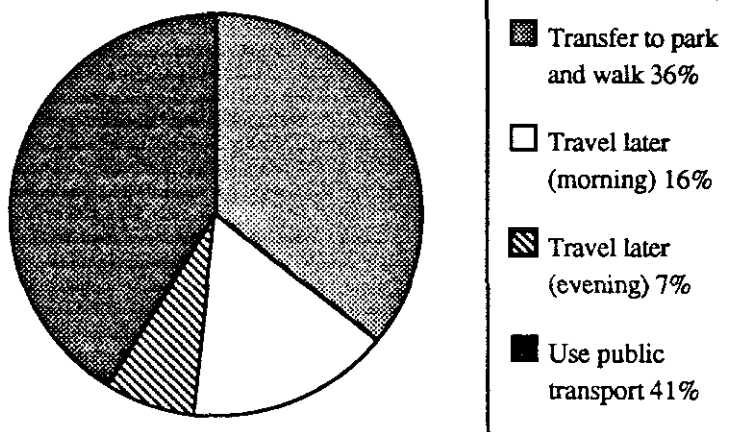
MTRU (1991) has investigated examples of area licensing in Singapore, Milan, Stockholm, and the Randstad in Holland. In most cases, vehicles entering the designated area are required to purchase a permit. The Singapore scheme, established in 1975, requires all vehicles entering the restricted zone to display a windscreen ticket. In addition, the original programme consisted of improvements to public transport, new traffic regulations and controls on car ownership. Car traffic into the restricted zone showed an immediate reduction of 71 per cent in the period 7.30 to 9.30 am, when licensing was applied. The longer-term effect has been a shift to off-peak travel, and a transfer to other modes for the commuting journey. The modal share of traffic held by cars diminished from 43 to 22 per cent between 1974 and 1988, whilst that of public transport increased from 46 to 63 per cent over the same period.

It should be emphasised that the Singapore road pricing scheme was operated as part of a *package* of measures, including an investment in new bus and rail facilities and controls on car ownership. An integrated approach such as this goes some way towards overcoming the potential difficulties of road pricing summarised by Whitelegg (above). The positive results achieved in Singapore add weight to the argument that policy measures to reduce travel demand are most effective if introduced as part of a strategic package.

MTRU has also investigated a system of area licensing in Milan, in which access to the city centre by car is not priced, but restricted to residents, businesses and emergency services. This is therefore a regulatory, rather than a market-based, application of area licensing. Introduced in 1985, the scheme is estimated to have reduced car traffic in the morning peak hours by between 40 and 55 per cent. An estimate of the modal breakdown suggests that 41 per cent of the diverted car traffic has been shifted to public transport, whilst 36 per cent transferred to 'park and walk'. The remainder is accounted for by altered travel times (see Figure 5.8).

The same study has documented the planned system of road pricing in Cambridge. The scheme will make use of electronic monitors fitted to cars, which deduct credits from a magnetic card whenever the car encounters congested conditions. It is estimated that traffic levels will be reduced by 30 per cent in the first year of operation.

Figure 5.8 Breakdown of modal transfer resulting from the Milan scheme



Source: MTRU, 1991.

Another form of road-pricing requires road users to pay a fee for using a particular road. By paying each time the road is used, the motorist is charged for the roadscape in proportion to his or her use of it. In recent years the idea of toll roads has been revived as a means of funding large roadbuilding projects. For example, the Northern Relief Road near Birmingham has been financed by private interests, who anticipate recovering their costs through charges levied on users of the road.

The use of toll roads has the potential for discouraging the use of cars as part of a wider transport or environmental strategy. However, it should be noted that toll roads schemes that have been proposed to date have been instigated not with environmental concerns in mind, but rather as a means of raising private capital for roadbuilding projects on an *ad hoc* basis.

Goodwin (1991) has proposed a 'Rule of Three' for allocating the proceeds of road pricing. It is suggested that road fees be divided equally between general tax revenue, road construction and maintenance, and public transport. Surveys indicate that the public regards road pricing more favourably if the proceeds are invested in public transport infrastructure, rather than being directed exclusively into new road programmes. The question of public acceptance is discussed more fully in section 5.7 below.

In summary, market measures have a considerable potential for curbing traffic demand. In many cases, an adjustment of present taxation structures would achieve results; beyond this, additional fiscal measures may be introduced. A system of new taxes can be made revenue-neutral, either within the transport sector or across the economy as a whole.

Market instruments are more likely to be successful if introduced as part of a *package* of measures, since such a strategy can exploit the synergies that exist between different policy instruments. For example, road pricing is more likely to achieve modal transfers if public transport is being subsidised at the same time. Evidence from road pricing surveys indicates that public acceptance tends to be greater if policies are perceived as part of a broad strategy with clear goals.

5.5.3. The role of investment in altering travel demand

Travel demand can also be altered through the use of investment, the third of the options categorised in 5.2.1. The role of investment is more relevant in altering travel demand than it is in promoting technological changes in the transport stock.

EXPANDED CAPACITY

In its simplest form, investment has a potential for increasing the capacity or attractiveness of various transport modes through capital spending. A key aim of any CO₂-reduction strategy is to achieve transfers from car and air travel to less carbon-intensive modes.

In May 1989 the government announced details of ‘a greatly expanded motorway and trunk road programme’, based on considerably increased estimates of road traffic up to the year 2025 (Department of Transport, 1989b). This programme is widely viewed as favouring road transport at the expense of other modes, particularly when it is noted that the majority of the capital is earmarked for the expansion of existing road capacity (Potter, 1992b). Investment in rail services, on the other hand, is directed predominantly at the renovation of existing capacity. Goodwin et al (1991) have catalogued some of the responses made by institutions to the roadbuilding programme. Among these, the Confederation of British Industry believes that the environmental benefits of public transport tend to be overlooked in the planning process:

... Rail investments may be relatively undervalued since adverse environmental consequences of road improvements are not financially assessed. Although the process is not mechanically applied, greater consistency in the criteria currently used by Government might encourage more rail investment. In due course it may be necessary for the social cost of CO₂ emissions to be recognised explicitly in the evaluation of both road and rail investments.

Current roadbuilding plans are based on a cost-benefit analysis, which has been criticised for its narrow view of costs and benefits. The absence of a proper cost-benefit appraisal in the assessment of public transport schemes is highlighted by Potter (1992b):

A particular target for criticism is the use of cost-benefit techniques to assess public investment in the roadbuilding programme whereas public transport investment is generally appraised on an internal financial basis. Even when wider criteria are occasionally included, allowances tend to be lower than for road building schemes and the methodology flawed. So, for example, a new motorway is evaluated by means of a cost-benefit analysis where the benefits (or returns) are relief of congestion, reduced journey time, reduced vehicle operating costs, reduced accident costs and environmental benefits to people where traffic noise and intrusion is reduced on existing roads. A new rail line on the same route however would be evaluated on purely commercial terms.

(Potter, 1992b)

As part of a strategy for reducing CO₂ emissions, the traditional appraisal methods for road projects could be revised in order to take into account, among other things, global environmental implications. In particular, a 'CO₂ audit' might be performed for proposed road schemes, and compared with similar assessments for public transport alternatives. Such an assessment process for transport projects would need to be undertaken in a strategic context, as part of a target-led initiative for controlling greenhouse emissions.

Evidence that investment in public transport can stimulate modal changes is scarce, although where such an investment has been made, the results are generally convincing. For example, a study of travel behaviour following the reopening of the Edinburgh-Bathgate line in 1986 found that although 60 per cent of journeys undertaken on the new service were formerly undertaken by bus, around 23 per cent replaced car journeys (Modern Railways, 1986). Moreover, the modal change took place almost immediately after the reopening of the line, suggesting that most of the effect on travel patterns takes place in the short term, with some additional transfers taking place in the longer term.

Further evidence for the modal change potential of public transport investment comes from opinion polls. A survey by MORI (Corrado, 1990) showed that in 1989, 32 per cent of drivers said that they would use their car less 'if public transport were better'.

Modal changes may be achieved by investing in new capacity, or by improving the quality of service provided by existing capacity. Government grants are an effective means of upgrading public transport systems. The LRT schemes currently under construction are supported by grants that are awarded by Government approval.

However, investment in public transport is not always sufficient on its own to achieve modal changes. Investment policies should form part of a broad, target-led strategy for improving transport provision overall. For example, the Leeds plan for developing LRT constitutes part of a wider strategy for switching commuter traffic from road to rail. By 2010, it is intended that every route into the city centre will have some form of rail alternative, with large park-

and-ride stations on the outskirts. Similarly, the Manchester tram scheme has a fares structure designed to attract car owners (Faux, 1991).

BUS PRIORITY SCHEMES

Transfers to less energy-intensive modes may be effected by a number of other investment programmes. Perhaps the simplest of all is the establishment of *bus priority* schemes. Figure 2.7 showed that buses are one of the most energy-efficient types of motorised travel available, and generally use less primary energy than railways. In their basic form, bus priority schemes involve bus lanes from which car traffic is banned during peak hours. Other forms include bus-sensitive traffic signals, which can electronically detect the approach of a bus, and change to green in order to let the bus pass without stopping. At the moment, the progress of buses in many cities is obstructed by congestion, caused mostly by private cars.

A key advantage of bus priority schemes in achieving modal transfer is that they can be implemented rapidly. In many cases, bus lanes already exist but require more effective policing to prevent their use by private motorists during congested periods.

TRAFFIC CALMING

In the urban environment, there is considerable scope for reducing the impacts of traffic through investment in *traffic calming*. In mainland Europe, traffic calming, or *Verkehrsberuhigung*, has for many years been a popular measure for improving the quality of residential and commercial areas (Whitelegg, 1990b).

Traffic calming generally involves redesigning the layout of roads with the intention of reducing traffic speeds and making travel easier for pedestrians and cyclists. In many cases obstacles are introduced to car traffic, including speed humps, flower beds, trees, chicanes and reduced speed limits. The movement of pedestrians is eased by the construction of road crossings and wider footpaths.

The motives for introducing traffic calming tend to be related to the quality of the urban environment. It is unlikely that traffic calming alone can offer a significant potential for improving fuel economy. Chapter Three showed that a typical car reaches its optimum fuel economy at a speed of around 70 km/h (44 mph), so measures to reduce the speed of urban traffic are likely to be associated with a fuel consumption penalty.¹ However, there are a

¹ The nature of many traffic-calming schemes is such that cars are required to accelerate and decelerate frequently. Cruder designs, such as speed humps, may actually encourage harsh and uneconomical driving

number of benefits which may be seen as justifying a small fuel consumption penalty. The author shares the view of Fergusson and Holman (1990):

Well designed traffic calming schemes are clearly beneficial to traffic management, particularly in the interests of preserving a pleasant local environment; but we do not consider that they offer significant benefits from the perspective of fuel economy.

The greatest value of traffic calming in reducing CO₂ emissions lies in opportunities for modal transfer. Proportionately, traffic calming increases the duration of short car trips more than long ones, and the attractiveness of walking and cycling increases for these journeys. Short trips are also where the efficiency of the car is at its worst, and the energy-saving potential of modal transfer is greatest. The potential for modal transfers is high: in Britain, one in eight car journeys is less than one mile (1.6 km) in length (Department of Transport, 1988).

In March 1992, the Traffic Calming Bill received Royal Assent, providing a legal framework in which local authorities may install traffic calming schemes. The result is likely to be a move away from the use of crude road humps, which are not always suitable for traffic conditions, towards other forms of obstacle such as chicanes, gates and shared spaces.

CONGESTION RELIEF

In urban areas a variety of policies are available for improving traffic flows. Chapter Three described a system of traffic management that coordinates individual vehicles with the green phase of traffic lights, thereby reducing the number of occasions on which vehicles need to stop at junctions. Similarly, *route guidance* technology can allow drivers to navigate using electronic beacons, obtaining information on the levels of congestion on different routes. By finding routes that are less congested, both average speed and fuel economy can be improved (GEC Autoguide, 1990).

Such technologies would probably be introduced using technology developed by private companies. It is likely that there would be considerable demand from motorists for a device that would reduce their journey times in congested areas, and companies such as GEC Autoguide are investing in the necessary infrastructure.

However, doubts have been expressed concerning the usefulness of such measures for freeing congested roadspace. To an extent, congestion is self-regulating, and any improvement in traffic flow will lead to more cars using a particular road. Thus empty

practices. A consideration of car fuel economy should ideally be taken into account in the design of traffic-calmed streets.

roadspace tends to be filled with traffic once more, and congestion returns. Mogridge (1985) believes that 'in conditions of suppressed demand, increasing the capacity of the road network merely shifts sufficient car-owning high-capacity network users on to the roads until road speeds are in equilibrium again'.

It is now widely accepted that in order to reduce congestion, it is necessary to tackle the *demand* for roadspace, rather than simply increasing the supply. A recent EC Green Paper on transport and the environment pointed out that: 'If there is congestion, planning should not necessarily seek to increase the road network, because this can lead to an increase in demand' (European Commission, 1992). Traffic management may only be beneficial in reducing CO₂ emissions if combined with demand management policies.

MARKETING PUBLIC TRANSPORT

In the 1980s, environmental concerns in Switzerland led to a campaign promoting public transport as a more socially acceptable form of travel. Hass-Klau (1990) has described the various market-based incentives that were deployed, which included positive advertising for public transport services, and special discounts and incentives for younger travellers. Similar campaigns were subsequently launched in Germany. Hass-Klau points out that advertising is only successful if accompanied by a substantial level of investment in the transport system being promoted:

... a combination of investing in public transport and a different style of marketing will show results. But the public transport network has to be very good, the interchanges excellent, the headways short and the facilities at high standards, all of which cannot be achieved without investing money.

5.6. Timescales of policy measures

The policy measures described in this chapter have a wide range of timescales, or 'lead times'. Technological measures that can be applied to vehicles are constrained by the rate of turnover in the vehicle market. Typically a car has a lifetime of between 10 and 15 years before it is replaced. More economical vehicles and alternative fuels could therefore only be introduced in a 'graded' fashion, with a time-lag of approximately ten years between the introduction of a policy and its ultimate fruition.

Technological measures can also be delayed by *institutional* processes. Regulations and major changes to the taxation system, such as the introduction of a carbon tax, can take several years to be approved by Parliament and set in place. On the other hand, adjustments

to the existing taxation structure, such as rebates and surcharges related to fuel economy, could be introduced in a single Budget statement.

Other policy measures are, by their very nature, more long-term in nature. A policy of energy conservation through land-use planning would take many years to achieve results, because of the delays involved. Even employer-based schemes for reducing travel demand would take time to have an effect, since employees are unlikely to alter their lifestyles and travel arrangements instantaneously. More immediate impacts could be achieved through measures such as bus priority schemes.

Although the more radical measures described above tend to have longer lead-times, this does not imply that they should be given less priority than other measures. An effective strategy might involve prioritising the longer-term measures, at the same time as instituting more immediate policies in the shorter term. In terms of CO₂ emissions, short-term policies such as incentives for fuel efficiency can be used to 'buy time' while more long-term measures such as land-use planning are set in motion.

This indicates the need for a strategic, target-led approach to reducing transport emissions, rather than a collection of piecemeal measures. The synergy between different policy measures can be as important as the measures themselves.

5.7. Public acceptance of policy measures

Public acceptability is a vital requirement of any policy for reducing CO₂ emissions from personal travel, for both ethical and practical reasons. In recent years, a number of surveys have been carried out to test public attitudes on various transport problems and their possible solutions.

As the 1992 General Election demonstrated, public opinion surveys are not necessarily a reliable indicator of real-life attitudes. For example, a survey by MORI (1990) showed that 47 per cent of drivers would buy a car with lower fuel consumption next time they change their car, in order to reduce CO₂ emissions. In reality the car market shows no sign of such a trend, with attributes such as performance, comfort and image continuing to have a more significant influence on purchasing decisions.

A survey of Londoners' attitudes to road pricing (MacKinnon, 1991) illustrates another important effect. When asked whether they would support road pricing in London, 43 per cent of respondents supported the notion, with 53 per cent against it. But when it was suggested that the money raised would be used to reduce congestion, the proportion in favour rose to 62 per cent. The context in which policies are introduced is thus an important influence on public acceptance.

These observations support the view that policies should be deployed as part of a wider strategy with a clear purpose. By making it clear to the public what the overall aim of the strategy is, and what the benefits will be, it is possible to create a more favourable impression of particular policy measures.

5.8. Deployment of policy measures

This chapter has provided a catalogue of options for reducing CO₂ emissions from personal travel. Table 5.6 is a summary of the policy measures that have been identified. These policies should not be regarded as distinct and independent of one another, since there are many interactions and secondary effects resulting from any particular policy measure. Nevertheless, it is possible to identify principal areas in which each policy will have an effect, and these are summarised in Table 5.7.

Table 5.6 Policy measures for use in controlling CO₂ emissions

1. *Introduction of fuel economy labelling for new cars, and regulations on the content of car advertisements;*
2. *Introduction of a 'feebate' scheme for new cars based on fuel economy;*
3. *Establishment of a long-term programme for the research, development and deployment of 'greenhouse-neutral' transport fuels, including incentives for consumers;*
4. *Enforcement of road speed limits, and possibly downgrading some existing limits, to improve average fuel economy;*
5. *Introduction of regulations requiring employers to reduce the travel demand of their workforce;*
6. *Establishment of an environmental assessment programme for proposed road schemes, whereby CO₂ emissions are compared under a number of different options;*
7. *Increased investment in, and subsidy for, public and non-motorised modes of transport (partly funded by cancelled roadbuilding schemes);*
8. *Redistribution of transport taxes to promote fuel economy, alternative fuels, modal transfer and reduced travel volume;*
9. *Business taxes to be related to a measure of accessibility for customers and employees;*
10. *Introduction of area licensing to discourage the use of cars in urban areas;*
11. *Establishment of strategic planning regulations for promoting local access, rather than encouraging highly mobile and energy-intensive lifestyles;*
12. *Introduction of a carbon tax to reflect the environmental cost of burning fossil fuels, and to reduce consumption.*

Table 5.7 Areas of influence for each of the policy measures

POLICY MEASURE	'Areas of influence'			
	Fuel economy	Alternative fuels	Modal transfer	Reducing travel demand
1. Fuel economy labelling/advertising	✓	×	×	×
2. Fuel economy feebates	✓	×	×	×
3. Alternative fuels programme	×	✓	×	×
4. Speed limits	✓	×	✓	✓
5. Employer-based travel schemes	✓	×	✓	✓
6. Environmental assessment of transport projects	×	×	✓	×
7. Increased spending on public transport	×	×	✓	×
8. Redistribution of transport taxes	✓	✓	✓	✓
9. Business taxes to reflect accessibility	×	×	✓	✓
10. Area licensing and road fees	×	×	✓	×
11. Land-use planning for reduced mobility	×	×	✓	✓
12. Carbon tax	✓	✓	✓	✓

There is evidence to suggest that *individual policy measures are more likely to succeed if deployed as part of a 'package' of measures*. The packaging of policies has two benefits. Firstly, the synergies that exist between various policies can be exploited, and the overall effect enhanced. Secondly, public acceptance of policy measures is more likely to be won if the measures form part of a strategy with clearly-defined benefits. In the worst case, some policies may be rejected by the public unless marketed in a suitable fashion.

The *timescales* of different policy measures can be given full attention if the policies are assembled as a single package. For example, measures to curb car use would ideally be implemented in the period following an investment in public and non-motorised transport modes.

The list of policies set out below provides a rationale for Scenario 2. This will be identical to Scenario 1, but with the addition of measures aimed at promoting fuel economy. What reduction in CO₂ emissions is possible using short-term, technological measures? How does this compare with the current British target of stabilising CO₂ emissions at 1990 levels by the year 2000?

Chapter Six

SCENARIO 2: BUSINESS AS USUAL PLUS 'TECHNICAL FIXES'

6. SCENARIO 2: BUSINESS AS USUAL PLUS ‘TECHNICAL FIXES’

“Efforts to improve energy efficiency will have to be strengthened if the goal of a significant absolute reduction in CO₂ emissions from energy-use is to be achieved.”

- Lee Schipper, 1991

6.1. The use of ‘technical fixes’

Scenario 1, Business as Usual, has shown that a continuation of present policies will result in substantial increases in CO₂ emissions from personal travel. In order to achieve reductions in emissions, policy changes will be needed.

This study has proposed two broad classifications for policy measures: Approach A, consisting of technological changes to the hardware and infrastructure of passenger transport; and Approach B, comprising changes to the structure and volume of personal travel. This chapter examines the potential of Approach A for alleviating CO₂ emissions from personal travel. A modification of ‘business as usual’, Scenario 2, is introduced, in which vehicle fuel economy and alternative fuels are vigorously promoted, with no change in the growth of travel demand.

An improvement in the specific energy consumption (SEC) of private cars can be achieved through a combination of better vehicle fuel economy and a shift in the vehicle stock towards smaller-engines. In addition, a growing proportion of cars may be run on ‘greenhouse neutral’ energy sources, of the types identified in Chapter Five.

The volume of travel demand in Scenario 2 is the same as in Scenario 1, as are the relative shares of mileage by different modes. However, the fuel economy of private vehicles progressively improves via the use of market-based incentives, as described in Chapter Five. Alternative fuels are assumed to enter the market as a result of similar incentives, supported by further development of the relevant technologies.

As indicated throughout this study, private cars may be considered a special case in terms of fuel economy. Unlike other modes, the average fuel economy of cars is considerably worse than the cost-effective maximum. Bus operators, rail companies and airlines use the most

economical vehicles that are available to them (within financial constraints) in the interest of minimising their operating costs.

In effect, Scenario 2 draws upon the first three items in the list of policies presented at the end of the previous chapter. Later on, Scenario 3 will investigate the combined effect of all twelve policy proposals.

6.1.1. Fuel economy feebates

Chapter Five showed that various market-based incentives may be deployed in order to promote the purchase of more economical cars. Scenario 2 will investigate the effect of policies designed to influence fuel economy alone. Policies that are likely to have a secondary effect on travel demand and modal choice, such as fuel taxes, are not included here.

Scenario 2 investigates the likely effect of a feebate scheme, of the type introduced in Ontario. Fees and rebates are added to car sales tax in order to reflect the fuel economy of different models relative to the average. This scenario embraces the first two measures in Table 5.6, namely a system of fuel economy labelling, and financial incentives for purchasers of economical vehicles.

COMPANY CARS

The previous chapter has shown that the taxation of company cars presently favours less economical cars, because the scale charges undervalue larger-engined cars more than they do smaller vehicles. A feebate scheme for the promotion of fuel economy should therefore address the taxation of company cars.

The reform proposed here is based on the feebate principle, but applied to company car users. Scale charges for a particular engine size category would be linked to fuel economy, with reduced charges for more economical cars and increased charges for less economical cars. The desired effect would be to reduce the engine size and fuel consumption of company-financed cars.

Potter (1992a) has proposed such a scheme, with scale charges related to fuel economy: details are given in Table 6.1.

Table 6.1 Illustrative example of a rebate/surcharge system for company car taxation

Engine size category	Scale charge increased by 25% if car's fuel consumption exceeds:	Scale charge decreased by 25% if car's fuel consumption is less than:
Up to 1.6 litre	8.1	5.7
1.6 - 2.0 litre	9.4	6.3
Over 2.0 litre	11.3	7.1

Source: Potter, 1992a

In the case of privately-purchased cars, the disadvantage currently suffered by diesel-engined cars as a result of their larger engine capacity would be removed, since the level of tax would be related not to engine size but to fuel economy. The level of company car taxation is still affected by engine size, although the disadvantage suffered by diesels is lessened by the fuel economy aspect. Diesel-engined company cars could be promoted by other means, such as the inclusion of all large diesels in the '1.6 - 2.0 litre' category.

PRIVATELY-PURCHASED CARS

A feebate scheme may be introduced to cover privately-purchased vehicles as well as company cars. The Ontario scheme, outlined in the previous chapter, involves fees and rebates that are payable on sales of new cars according to their fuel consumption. Scenario 2 will adopt a revenue-neutral feebate system modelled on the Ontario scheme, where the revenue raised by the surcharges would provide funding for the rebates and for the programme's administrative costs. An illustrative example of the proposed system is outlined in Table 6.2.

It is assumed here that the targetted scale charge feebates would cause the car purchasing decisions of companies to be affected in the same way as those of private individuals. In other words, the fees and rebates payable on new cars will have the same effect across the whole market, regardless of whether a car is purchased privately or by a company.

Table 6.2 Illustrative example of a feebate scheme for car sales in Britain

Car fuel economy (l/100km)		Surcharge or rebate
Over	Not over	
	6.0	£500 rebate
6.0	7.0	£100 rebate
7.0	9.0	£100 surcharge
9.0	12.0	£1,000 surcharge
12.0		£5,000 surcharge

6.1.2. Setting the level of incentive

In the absence of empirical evidence, the necessary level at which financial incentives should be set is difficult to evaluate with precision. Achieving revenue-neutrality is doubly difficult, because not only is the effect of incentives on car purchase decisions poorly understood, but any change in purchasing behaviour will shift the balance between rebates and surcharges.

In practice, an 'iterative' methodology is therefore most appropriate, in which taxes and subsidies are initially set at an estimated level, and revised annually on the basis of past performance (see 5.2.3). The precise mixture of fees and rebates cannot realistically be determined with great accuracy, and should therefore be assessed annually. Such an appraisal and adjustment could be performed as part of the annual Budget. The level of fees and rebates for different fuel economy categories would be revised alongside the annual adjustments to other taxes.

6.1.3. The assessment of fuel consumption for different models

The fuel consumption of a particular make and model of car is clearly defined by the official test figures published by the Government. Watson (1989) has derived a formula that relates these test data to real life fuel economy, using a statistical technique. This 'converted' figure may be used to provide a single fuel economy value for each car model, to be used in assessing the fuel economy of different models for the purposes of these two policy measures.

The formula for converting official test results to actual, on-road fuel economy is given as follows:

$$\text{Consumption} = 0.240 F_u + 0.308 F_{90} - 5.47 \text{ ENG} + 20.615$$

where Consumption is the average on-road fuel consumption, F_u and F_{90} are the official list consumptions in the urban cycle and at a steady 90 km/h, and ENG is the engine size in litres. All consumption figures are in miles per gallon (mpg).

The formula applies only to petrol-engined cars. There is no reason why a similar formula might not be derived for diesels, thereby allowing the 'actual' fuel consumption to be calculated for both petrol and diesel-engined vehicles. In this way a single fuel economy figure may be derived for all cars on the road, and this figure used to determine the level of the sales tax surcharge or rebate.

6.1.4. Fuel economy labelling and advertising

Fuel economy labelling for cars, together with a change in the emphasis of car advertisements away from performance and towards economy, is expected to take place as a direct result of the fuel economy incentives introduced in this scenario. However, labelling needs to be standardised by means of government regulations, in order that the car buyer can make valid comparisons between models.

It is proposed that a standard method of calculating a single fuel economy figure be devised, based on the official data that are available for all cars. All new cars would display a notice indicating the official fuel economy value, alongside the fee or rebate that is payable at the time of purchase in accordance with the fuel economy incentives described in Scenario 2.

6.1.5. An alternative fuels programme

Scenario 2 also includes a programme for the research, development and deployment of alternative-fuelled vehicles that can be considered 'greenhouse-neutral'. The options for such vehicles have been identified as electric or hydrogen vehicles charged using renewable energy, and vehicles running on renewable biofuels.

It is unrealistic to suppose that the entire car stock could be replaced with alternative-fuelled vehicles by the year 2025. There are severe technological difficulties associated with such a transformation, not least of which is the availability of sufficient quantities of renewable energy.

Instead, it is expected that alternative fuels will be introduced as part of a target-led programme of incentives, coupled with research and development. It is assumed that alternative-fuelled vehicles will begin to enter the market in 2005, with 10 per cent of the

national car fleet running on 'greenhouse-neutral' sources of energy by the year 2025. The growth in alternative fuels is likely to continue thereafter, with the alternative fuels fraction of vehicles reaching 100 per cent in the very long term as supply shortages drive up the price of petroleum.

6.2. The effect on the car stock

A strategy for promoting vehicle fuel economy would have two effects on the car stock. Firstly, purchasing patterns would change: some purchasers would be willing to pay more for large-engined vehicles, whilst others would shift to more economical cars. Overall there would be a net increase in the average fuel economy of new cars, including an increase in the fraction of cars that are diesels.

Secondly, the fuel economy of a particular engine size would improve as manufacturers placed more emphasis on fuel economy and less on performance. The net result would be a gradual increase in the average fuel economy of the nation's car stock, becoming more pronounced as old cars are replaced by new.

6.2.1. A target-led strategy

The approach recommended here is a 'target-led' strategy. Firstly, the distorting effect of the company car system is removed, by following the steps described in 6.1.1 above. Next, a target for an annual improvement in new-car fuel economy is agreed, and the feebate scheme is deployed across the whole car market (company and privately-purchased) to achieve this goal. In this way the level of fees and rebates can be adjusted each year in order to match the desired target.

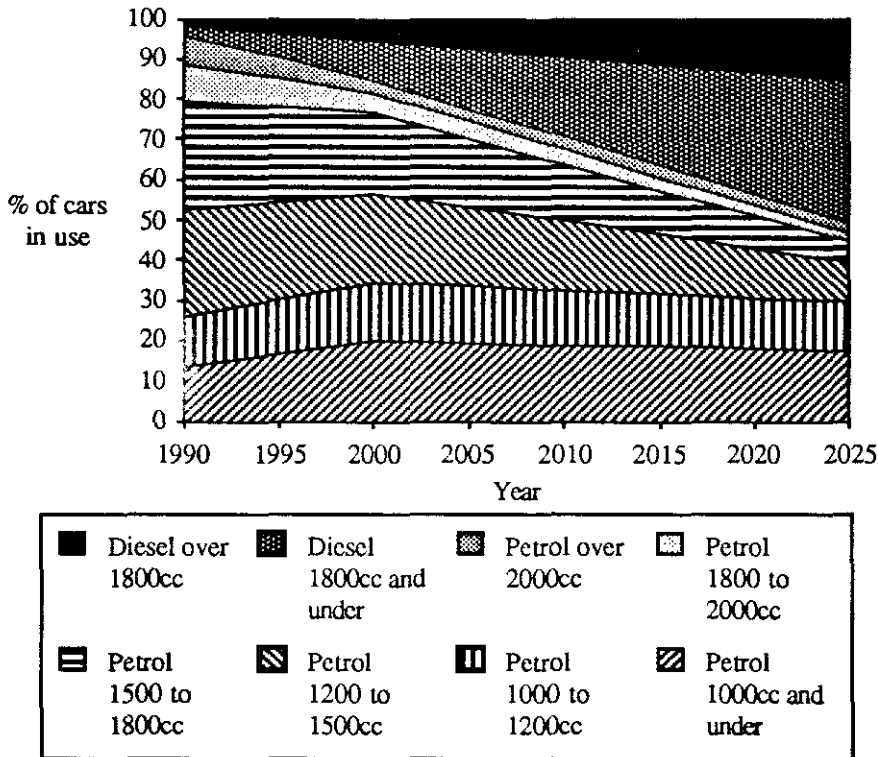
6.2.2. The effect on engine capacities

The effect on purchasing patterns is modelled by altering the distribution of engine capacities. No examples of fuel economy incentives have been in force for long enough to predict the exact effect on car purchases of the two measures introduced here, so an estimate is made (see Figure 6.1) of the change in the car stock that would be brought about by the market instruments deployed in this scenario. These trends are not based on observations, but instead represent an estimate of the changes in purchasing patterns that could be achieved by a feebate scheme.

The estimated distribution of engine types shown in Figure 6.1 assumes the greatest 'reasonable' change that might be expected to occur, given the time-lag involved in changing the car stock. Cars currently in use would need to be allowed to work through the system, and the process of altering car-purchasing decisions is assumed to take place gradually, so that the distribution of cars shown at the right-hand side of the chart is eventually reached.

The number of diesel cars, particularly those of engine capacity 1800cc and under, increases markedly, whilst within the petrol-engined categories there is a gradual shift towards cars with smaller engine capacities.

Figure 6.1 Engine capacity distribution resulting from fuel economy measures



6.2.3. The effect on the fuel economy of different engine sizes

As well as changing the pattern of engine capacities, fuel economy measures will influence the fuel economy of particular engine sizes. The Department of Energy (1989) has introduced the concept of *benchmark* fuel economy. For each engine size category, it lists the 'benchmark' fuel economy, defined by what is technically possible in that engine size.

Benchmark fuel consumption represents 'a car design and performance characteristic which is already available in the car market within each category of engine capacity', calculated as 'the 20th percentile of each distribution of overall fuel consumption in each vehicle category'. Table 6.3 compares 'average' and 'benchmark' fuel economy in 1986.

Scenario 2 assumes that in the period 1990 - 2005, the market measures outlined above lead to a gradual transition from average fuel economy to benchmark fuel economy: the average moves to the 'state of the art'. Table 6.4 shows the effect of this trend on the fuel economy of different engine capacities. In addition to the minor improvements in fuel economy associated with 'business as usual', there is an additional improvement resulting from the transition from average to benchmark.

Table 6.3 Average and 'benchmark' fuel economy, 1986 (l/100km)

<u>Vehicle category</u>	<u>Average fuel economy</u>	<u>'Benchmark' fuel economy</u>
Petrol-engined		
Up to 1000 cc	7.6	6.2
1001 - 1200 cc	8.3	6.7
1201 - 1500 cc	8.9	7.1
1501 - 1800 cc	9.8	7.4
1801 - 2000 cc	10.6	7.9
Over 2000 cc	13.7	9.8
Diesel-engined		
Up to 1800 cc	6.4	5.4
Over 1800 cc	7.7	6.6

Source: Department of Energy, 1989.

Table 6.4 Fuel economy improvements assumed in Scenario 2 (l/100km)

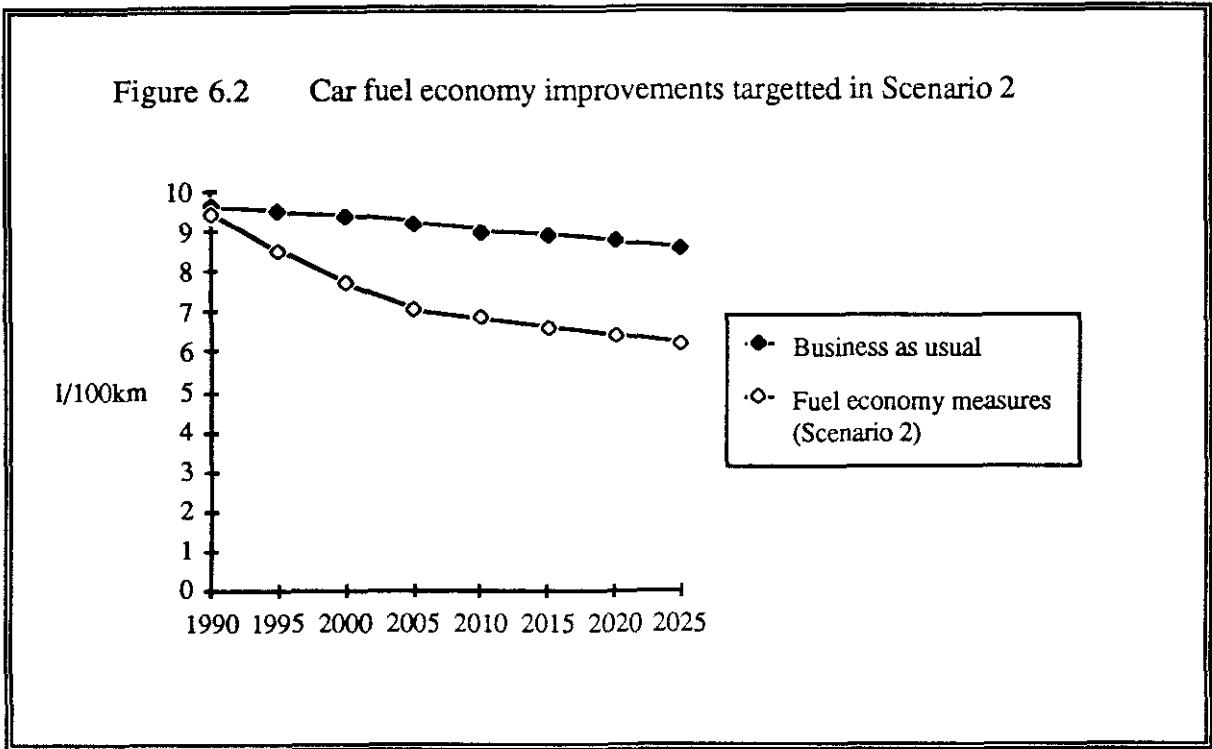
	1988	1990	1995	2000	2005	2010	2015	2020	2025
Petrol-engined									
Up to 1000 cc	7.60	7.54	7.09	6.64	6.18	6.04	5.90	5.76	5.62
1001 - 1200 cc	8.30	8.23	7.71	7.19	6.67	6.51	6.36	6.21	6.06
1201 - 1500 cc	8.90	8.83	8.24	7.65	7.06	6.90	6.74	6.58	6.42
1501 - 1800 cc	9.80	9.72	8.94	8.16	7.39	7.22	7.05	6.88	6.72
1801 - 2000 cc	10.60	10.51	9.63	8.76	7.88	7.70	7.52	7.35	7.17
Over 2000 cc	13.70	13.59	12.32	11.05	9.78	9.56	9.34	9.12	8.90
Diesel-engined									
Up to 1800 cc	6.40	6.31	5.97	5.64	5.30	5.18	5.06	4.94	4.82
Over 1800 cc	7.70	7.60	7.25	6.89	6.54	6.39	6.24	6.09	5.94

6.2.4. The effect on overall fuel economy

Based on the level of improvements described above, the target adopted for Scenario 2 is *an annual increase of four per cent in average new-car fuel economy over a period of five years*. This corresponds to an eventual improvement of 20 per cent in the fuel economy of the whole car stock. The car stock is assumed to be replaced completely after 15 years. After 25 years, the improvement rises to 38 per cent, as a result of ongoing improvements in fuel efficiency and further changes in purchasing behaviour. Figure 6.2 compares the improvement in fuel economy implied by this target with the business-as-usual trend that was seen in Scenario 1.

The target for improved fuel economy illustrated in Figure 6.2 is seen as a realistic estimate of the possible improvement in car fuel economy that could be brought about using market-based incentives. It is viewed as conservative, reflecting the practicability of the projected change. The increase in fuel economy would take place as a result of a net shift towards smaller engine sizes, plus technical improvements *within* engine size categories towards benchmark fuel economy.

Figure 6.2 Car fuel economy improvements targetted in Scenario 2



6.2.3. The effect on car travel demand

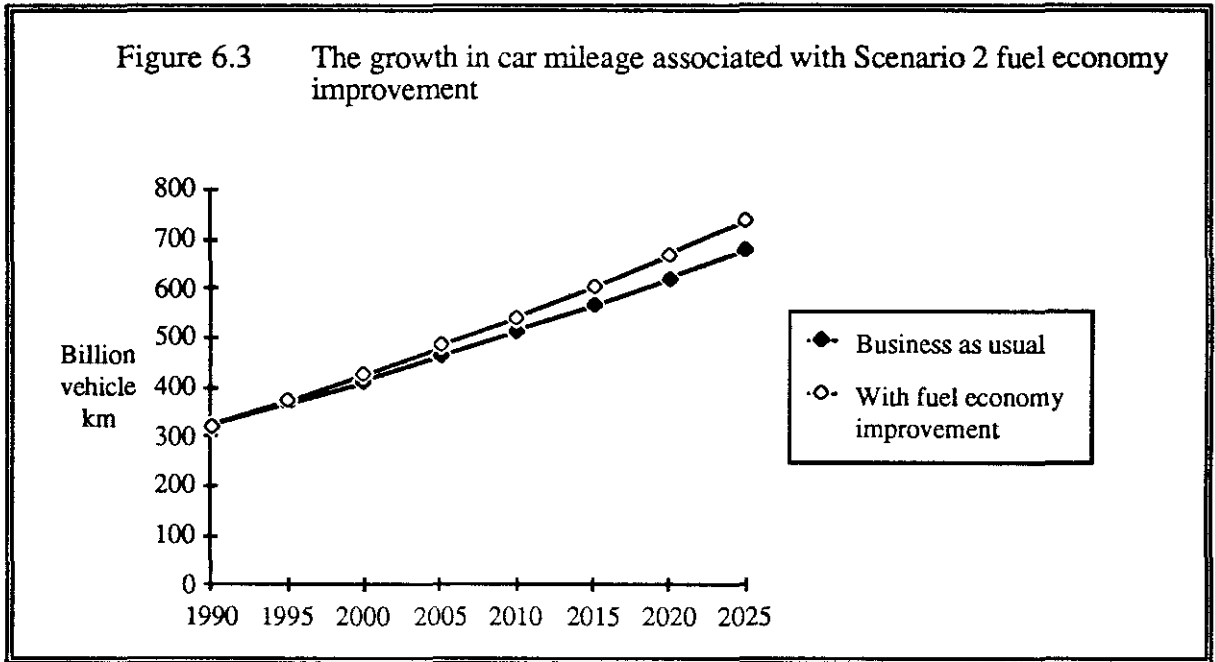
As noted in Chapter Six, improvements in vehicle fuel economy can lead to an increased demand for travel. This is based on the fact that travel demand is constrained by the monetary cost of travel. A reduction in the cost per mile of using a car therefore leads to an increase in mileage, with overall expenditure the same as before.

Scenario 2 takes account of this effect by adopting an estimate of the elasticity of traffic level with respect to fuel price. In this instance, an 'equivalent' reduction in the price of fuel is calculated, based on the improvement in car fuel economy. Goodwin (1988) quotes figures for the elasticity as 0.13 (short run) and 0.31 (long run), based on an amalgamation of other estimates. The figures are accompanied by a caveat which draws attention to the small number of studies on which they are based, as well as the widely varying results that they produced.

The SPACE model assumes that the elasticity of car travel demand with respect to fuel cost will increase linearly between the short and long-run values.¹ For each year, it combines the elasticity with the equivalent reduction in fuel cost, and derives a figure for the increase in traffic level resulting from the improvement in car fuel economy.

¹ The assumption of linearity is broadly consistent with the findings of Goodwin (1988)

The results of this process are shown in Figure 6.3. The lower line on the graph shows the business-as-usual growth in car mileage, as it appears in Scenario 1. The upper line depicts the growth in car mileage associated with enhanced fuel economy, as in Scenario 2.



The effects of the two policies introduced in this scenario are now evaluated. The SPACE model is used to project the CO₂ emissions that result from the improvement in car fuel economy, and resulting increase in travel demand, calculated above.

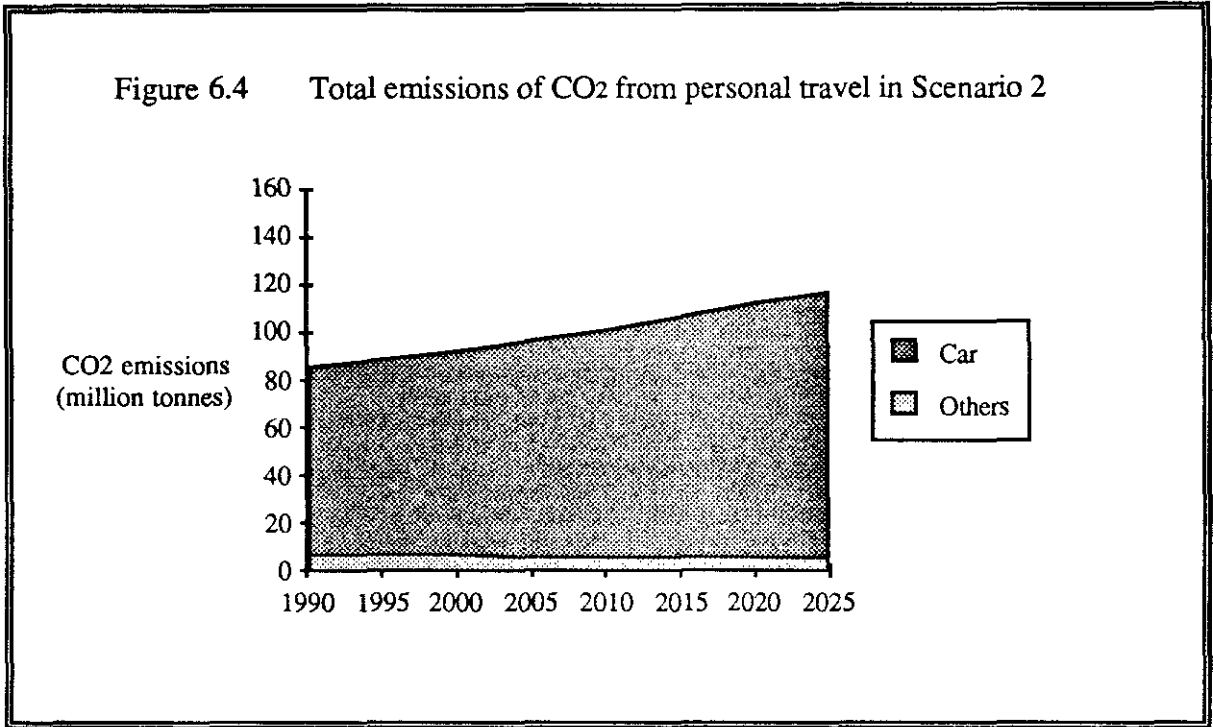
6.2.4. The growth of the 'greenhouse-neutral' car stock

The alternative fuels programme introduced in Scenario 2 permits only energy sources that may be considered 'greenhouse-neutral'. This limits the options to electric and hydrogen vehicles running on renewable sources of energy, and heat-engined vehicles running on biofuels.

As explained earlier in the chapter, it is expected that the first alternative-fuelled vehicles would enter the market in 2005, and that the market share reaches 10 per cent by 2025. The growth would continue thereafter, beyond the range of the SPACE model.

6.3. Results of Scenario 2

The outcome of Scenario 2, in terms of passenger transport's total emissions of CO₂, is given in Figure 6.4. Emissions increase less rapidly than they did in Scenario I, but nevertheless show a growth of 35 per cent in the period 1990 to 2025. Of particular interest is the shape of the graph before and after the year 2005.



The figure shows that technological changes to the car stock are not capable of holding emissions down to their 1990 level up to the year 2000. Emissions of CO₂ increase by 12 per cent in the period 1990 to 2005. Thereafter, they begin to rise slightly more steeply, as the benefit of fuel economy improvements comes to an end. The increasing number of 'greenhouse-neutral' vehicles to some degree holds down the long-term growth in CO₂ emissions; but throughout the period 2005 to 2025, the ongoing growth in traffic volume forces upwards the annual production of CO₂.

6.3.1. Implications for national CO₂ targets

The results of Scenario 2 have important implications for the setting of national 'greenhouse' targets. The 'technical fix' scenario is not capable of reducing emissions to the 1990 level by the year 2000, the target of the UK Government and the European Community. In the period 2005 to 2025, the growth in emissions becomes slightly less pronounced. This is because

fuel economy measures are reaching their limit, although the alternative fuels programme is beginning to have an effect.

A more thorough transfer to 'greenhouse-neutral' energy sources is unlikely over the timescale of the model, since the technological limitations and restricted availability of suitable fuels would prohibit such a change. In the timescale of the SPACE model, there is therefore a need for complementary measures to be adopted. These would allow emissions to be stabilised by 2000, in line with the present Government target. They would also provide a means of holding down emissions beyond 2000, as technological measures alone are not capable of reducing CO₂ output.

Of course, a stabilisation in CO₂ emissions does not constitute a stabilisation in the atmospheric concentration of this gas. This can only be achieved through a substantial *reduction* in emissions (see Chapter One). The IPCC report (Houghton et al, 1990) estimates that a 60 per cent cut in CO₂ emissions worldwide will be needed if the atmosphere is to be stabilised at present concentrations. Chapter Seven will formulate a strategy by which the passenger transport sector can contribute to this more stringent goal.

Chapter Seven

SCENARIO 3: ATMOSPHERIC STABILISATION

7. SCENARIO 3: ATMOSPHERIC STABILISATION

“Since the affairs of men rest uncertain,
Let’s reason with the worst that may befall.”

William Shakespeare

7.1. The need for a more stringent target

Scenario 1 showed that ‘business as usual’ implies a substantial increase in emissions of CO₂ from personal travel. Scenario 2 investigated the effect of technology-based measures, in the form of fuel economy and alternative fuels, on this growth, and found that they could only partially offset the effect of increased travel volume.

These results indicate that CO₂ emissions from personal travel can only be effectively controlled through the deployment of both technological measures and changes in the nature of travel demand. In terms of the methodology introduced at the beginning of Chapter Five, this implies that policy measures from both Approach A and Approach B will be needed, introduced as a target-led package.

The IPCC assessment (Houghton et al, 1990) suggests that emissions of CO₂ from all sources should be reduced by at least 60 per cent from the 1990 level in order to stabilise the atmospheric concentration of this gas (see Table 1.4). This chapter aims to establish a scenario in which personal travel policies can contribute to the ‘atmospheric stabilisation’ target.

Having established a national target of reducing CO₂ emissions by 60 per cent, it is necessary to ascertain the reductions in emissions that should be undertaken by different sectors (industry, domestic, commercial and transport). The extent to which different sectors should reduce their individual emissions can only be established by a detailed analysis of each sector in turn. Such an exercise is beyond the scope of this study. However, indications from Germany suggest that, in the event of such an allocation, the transport sector would be allotted a less stringent reduction target than other sectors (see 5.1). The German proposals suggest that transport should achieve a nine per cent cut as part of a national policy to cut emissions by 25 per cent. By scaling-up these figures to the IPCC’s

target of 60 per cent, it follows that transport would need to achieve a reduction of approximately 20 to 25 per cent.

7.1.1. The ultimate objective: a 60 per cent reduction in emissions

This chapter will evaluate the level of emissions that is likely to result from the deployment of both technological measures and policies aimed at modifying travel demand. The ultimate objective is to reduce emissions of CO₂ by up to 60 per cent, in line with the IPCC target for atmospheric stabilisation. However, a more realistic target for the transport sector might be 20-25 per cent, as explained above.

The IPCC recommendation of a 60 per cent reduction in emissions does not specify a target date; instead, it represents a level of emissions that can be regarded as not producing a warming effect. For this study, the year 2025 is adopted for the full reduction in emissions. A period of 30 years would permit the implementation of most available policy measures.

7.1.2. Aspects of growth in travel demand

Scenario 2 has shown that technological measures, in the form of fuel economy improvements, are inadequate to reduce, or even to stabilise, emissions of CO₂ from personal travel. Changes in the nature of travel demand are required in addition to 'technical fixes' if appreciable reductions in emissions are to be achieved

Historically, three factors have led to the present volume of car usage:

- ❑ Rising car ownership leading to a transfer to car from other modes of transport;
- ❑ Rising car ownership leading to the generation of additional trips;
- ❑ Rising car ownership leading to a lengthening of the average trip (an increasingly important effect).

The contribution of the last two of these factors has increased in importance. In terms of reducing emissions, simple modal transfers to more energy-efficient modes offer a limited scope, because the historical growth in car use has led to a pattern of travel demand that could not be catered for by other modes. However, if public and non-motorised transport were expanded to their maximum possible modal share, a significant volume of car travel could be eliminated. In urban areas, car trips for shopping, work and leisure purposes could be replaced with walking and cycling, by means of a transfer to more local facilities.

It is therefore necessary to look beyond simple modal transfers as a means of influencing travel behaviour, and consider ways of reducing travel demand. Policies of this type are often termed *transport demand management*. A reduction in travel volume can be achieved by addressing the second and third of the areas identified above.

This chapter describes a third scenario, which contains policy measures for altering both the volume and the modal distribution of personal travel. The policy proposals introduced in Chapter Five are assessed and entered into the SPACE model. It is assumed that the technological measures introduced in Scenario 2 are retained in Scenario 3. Scenario 2 investigated the first three policy proposals presented at the end of Chapter Five; Scenario 3 will embrace the full list of twelve policy measures.

7.2. Policy measures for the stabilisation of atmospheric CO₂

Different policy measures will have different geographical and sectoral impacts. Some, like area licensing, will have an effect predominantly in city centres, with little impact elsewhere. Others, like the redistribution of transport taxes, will affect the use of cars everywhere, although there may be geographical variations in response. Similarly, some measures will affect certain types of journey purposes, or groups of people, more than others. For example, traffic calming would tend to affect travel modes for short, local trips rather than for longer journeys. This is because the proportion of a long trip affected by traffic calming will be insignificant, whereas a short trip may take place almost entirely in a traffic-calmed area.

7.2.1. ‘Packaging’ of policy measures: experience from Singapore

Evidence from overseas suggests that policy measures for altering travel demand may be more effective, and more likely to be accepted, if deployed as part of a strategic package (Metropolitan Transport Research Unit, 1991). For example, an area licensing scheme is more likely to be successful, and to be accepted by the public, if it is accompanied by an increase in the availability of high-quality public transport.

Scenario 3 contains a collection of policy measures, none of which is regarded as extreme in magnitude. The philosophy underlying this scenario is that a ‘package’ of largely tried and tested policy measures is a promising approach to reducing CO₂ emissions, particularly when public and political acceptability are taken into account. By contrast, individual policies applied in drastic form, such as a several-fold increase in fuel price, may be regarded as unacceptable both by governments and by the people that they serve.

An example of a comprehensive collection of measures aimed at reducing urban congestion is the scheme introduced in Singapore in 1975 (see 5.5.1). This comprised:

- ❑ Area licensing for the central urban zone;
- ❑ An increase in the number of buses in operation, and dedicated bus lanes;
- ❑ A 67-kilometre rapid transit system with 42 stations;
- ❑ A new by-pass avoiding the city centre;
- ❑ Traffic management measures including 'smart' traffic signals, parking regulations and one-way systems;
- ❑ Substantial taxes and restrictions on car ownership.

Although not all of these measures would be acceptable in Britain, particularly the restriction of car ownership, it is clear that this package has provided a solution to many of Singapore's traffic problems. The result has been a substantial reduction in the volume of traffic entering the city during the morning peak period and exiting in the evening. Traffic speeds have been increased by as much as 30 per cent, while the modal share of travel held by car has been halved. Between 1974 and 1990, car traffic was reduced by 65 per cent (MTRU, 1991).

This study acknowledges the complementary, synergistic effect of several policy measures, particularly in the urban context. Later in this chapter, a package of measures is proposed for deployment in urban areas.

7.3. Assessment of policy measures

The policy measures contained in Scenario 3 are examined in detail in this chapter, and assessed in terms of cost, acceptability and timescale. The aim of this scenario is to assess the potential for reducing emissions by all means available, namely technological measures, modal changes, and reductions in travel demand.

The following analysis is not intended to provide exact predictions of what will happen as a result of each policy measure; instead, it takes the form of an evaluation of the likely effects based largely on empirical evidence from schemes that are already in operation. The main purpose is not to develop each policy area in fine detail, but to identify which measures or combination of measures have the greatest potential to contribute to a strategy for reducing CO₂ emissions. The criteria by which policy measures will be assessed are effectiveness, acceptability, cost, and the need to maintain personal access.

7.3.1. Redistribution of transport taxes and a carbon tax

Chapter Five proposed, among other things, that the present system of transport taxation be rearranged in order to encourage energy conservation. One of the basic principles is the replacement of 'flat-rate' taxes with charges that reflect environmental impacts. It also recommended the introduction of a carbon tax on fuels, which would serve to encourage the use of less carbon-intensive sources of energy.

Scenario 2 showed how environmental taxation could be used to affect the choice of vehicle, in the form of incentives for economical and alternative-fuelled vehicles. The principle is extended in Scenario 3 and used to influence not only the characteristics of the vehicle stock but also the nature of travel *demand*. This section will examine the role of a revised system of transport taxes, including the introduction of a carbon tax.

Vehicle Excise Duty (VED), presently charged at £110 per year (or £60 for six months) for cars and light vans, could be eliminated and replaced with an additional fuel tax. This would make fuel economy a more important aspect of car purchasing decisions than at present, and so reduce the average fuel consumption of cars entering the market. This measure would also encourage more economical driving practices, as well as other effects such as reduced journey lengths and transfers to other modes.

In 1990, there were 21,989 thousand vehicles registered in the category 'private and light goods'. Taxation of these vehicles produces an annual revenue of approximately £2.5 billion. At current rates of consumption, this amount could be raised by adding approximately 8p to the price of a litre of fuel.

A further addition to the price of transport fuels can be brought about through the introduction of a carbon tax. One of the benefits of this tax is that it affects a broad variety of activities, sending a general but clear energy conservation message to consumers. The travelling public would have a variety of options for reducing fossil consumption, including using a more economical car, trip sharing, transferring to less polluting modes of transport, or reducing their overall travel distance. Some people may make no changes to their travel behaviour, and instead pay the additional cost.

The EC has proposed the gradual introduction of an energy tax equivalent to \$10 on a barrel of oil, to be introduced gradually over the period 1993 to 2000. This approximates to 7p added to the price of a litre of petrol. Britain has agreed in principle to the levy, which would generate revenue equally from non-renewable fuels and from fossil fuels according to their carbon content (Gardner, 1991). It is proposed in this scenario that the EC energy tax is introduced as proposed. The carbon tax in this scenario is deliberately set at a moderate level, in order to reduce the risk of public and political rejection.

The combined effect of transferring VED to fuel taxes and introducing a new carbon tax would therefore be to add approximately 15p to the price of a litre of petrol. This is seen by the author as a fairly modest price increase, particularly when compared with the recommendations of some environmentalists in the field. A much larger increase in fuel price, of the order of 500 per cent rather than approximately 30 per cent as proposed here, would have a vastly more significant influence on travel behaviour. However, the approach favoured by this study involves the use of fairly modest measures which, when packaged together, are likely to be of value in curbing greenhouse emissions. It is also recognised that a several-fold increase in fuel price would be seen by most governments as electorally disastrous.

The question of equity should be addressed when considering increases in the cost of travel. A frequently-heard argument against raising fuel prices is that people living in rural areas, particularly those on low incomes, will suffer unduly as a result of their dependence on the car. However, the package of measures put forward in this study offers most people benefits as well as costs, including an improved standard of public transport. In addition, it is possible for rebates to be made available to those groups in society for whom changes in the cost of travel are seen as inequitable.

As indicated in Chapter Six, Goodwin (1988) cites a demand elasticity of 0.30 (long run) and 0.13 (short run) for car traffic with respect to fuel price. These figures are for fuel price changes introduced in isolation, and not as part of a package of measures. They may therefore be considered a conservative estimate of the effect of fuel price policies that are applied as part of a package of complementary measures. Based on Goodwin's values, the 15p price increase would eventually lead to an eight per cent cut in car travel. This reduction would be distributed between modal transfers, car sharing, reduced journey lengths and eliminated journeys.

Consideration is given to the relative elasticities of different journey purposes. The SPACE model divides journeys into four categories of purpose: 'work', 'shopping and personal business', 'social and entertainment', and 'holiday and other'. For journeys to work, it might be expected that the routine nature of the travel, coupled with the easy availability of public transport, would lead to a relatively high elasticity of traffic with respect to fuel price. However, two factors act against this.

Firstly, the opportunity for modal transfer may be limited as a result of capacity constraints in the public transport system. This effect can be seen on the rail network around London, which in some areas is used beyond capacity. Secondly, although there may be opportunities for modal transfer, there is unlikely to be a significant potential for trip shortening or elimination, as commuters tend to be 'tied' to particular workplaces and working hours.

It is therefore expected that work trips will be less elastic than shopping and personal business trips. In contrast with workplaces, most shops or services can be found at a choice of locations. Entertainments and social trips, as well as holiday and 'other' journeys, are considered to lie between these two in terms of their elasticity.

The following variations on Goodwin's elasticities are thus assumed:

Work:	0.10 (short term), 0.25 (long term);
Social and entertainment:	0.13 (short term), 0.30 (long term);
Holiday and other:	0.13 (short term), 0.30 (long term);
Shopping and personal business:	0.20 (short term), 0.40 (long term).

Secondly, it is also likely that the elasticity of car traffic varies between different types of area. For people living in rural areas, the opportunities for reducing car travel are likely to be less than in urban and suburban areas. The average elasticity of 0.13 (short term) and 0.30 (long term) is thus taken to be comprised of the following components:

Rural:	0.10 (short-term), 0.20 (long-term);
Intermediate:	0.13 (short-term), 0.30 (long-term);
Urban:	0.15 (short-term), 0.35 (long-term).

It was indicated above that the reduction in car traffic would be brought about by a combination of modal transfers, increased car occupancy, reduced journey length and a decline in trip numbers. These effects are incorporated into the SPACE model as follows.

Firstly, it is assumed here that the 15p increase in fuel price would lead to a 'freeze' on car occupancy levels at their 1990 values, bringing to a halt the gradual reduction in load factors that has taken place in recent years. Historically, rising car ownership has led to a reduction in car occupancy. The increased fuel cost is assumed to encourage a degree of car sharing for all trip types, stabilising car occupancy from the year 1995.

The remaining reduction in car traffic is assumed to be distributed equally between modal transfer, journey shortening, and journey elimination. This implies that journey frequencies are reduced by twice as much as journey lengths at an aggregate level. For example, a particular category of car trip might decline by six per cent in frequency and by three per cent in length, resulting in an overall reduction of nine per cent in mileage. At a more detailed level, the degree of reduction varies according to the journey type and geographical area, as described above.

The SPACE model expresses travel in terms of trip numbers and trip frequencies (see Chapter Four). Each line of the model, representing a different combination of journey type and area, was adjusted according to the above criteria in such a way that (a) overall

passenger kilometres by car fell by eight per cent, and (b) trip numbers fell by twice as much as trip lengths.

It was also necessary to *add* passenger kilometres to the spreadsheets for the four other modes, in order to take account of the modal transfers which accounted for one third of the reduction in car travel. The individual lines of the spreadsheets were adjusted upwards, using the same methodology as that used to reduce car travel.

In all cases, the policies were assumed to be implemented immediately, with the full effect being achieved by the year 2000.

A 15p increase in fuel price would also have an effect on the average fuel economy of the car stock. Figures quoted by Goodwin (1988) imply that car fuel economy has an elasticity of 0.43 with respect to fuel price. This figure is derived from the difference between the fuel consumption elasticity and the traffic elasticity.

Combining the 15p increase in fuel price with the elasticity of 0.43 therefore gives a fractional increase in fuel economy for the car stock as a whole. This figure is translated into a reduction in fuel consumption for each year in the SPACE model, which is then subtracted from the existing average fuel economy value for that year.

As part of the redistribution of existing transport taxes, attention is also given to the system of company car taxation. Scenario 2 included the use of taxes that might influence the fuel economy of company cars, but did not examine other subsidies that are available. In particular, the subsidisation of fuel and the use of mileage bands in tax scale charges presently encourage company motorists to drive more than their non-subsidised counterparts. Seventy per cent of mileage undertaken by company cars is for non-business purposes (Potter, 1991c).

The objective of the taxation reforms proposed here would be to reduce the private mileage travelled by company car drivers to the level presently associated with non-company cars. The 30 per cent of mileage travelled for business purposes is assumed to be unaffected by changes in the taxation structure.

Scenario 3 includes the replacement of the present system of fuel scale charges with one in which fuel is taxed in proportion to the amount consumed, as proposed by Potter (op. cit.). Presently, the undertaxation of company motoring leads to an additional 2,735 km being travelled by each company car per year (Fergusson, 1990). In Scenario 3, this excess is eliminated, leading to an immediate reduction of 10.4 billion car kilometres overall. This reduction is applied to the final figure for car mileage after it is entered in the summary spreadsheet.

7.3.2. Enforcement of speed limits

Chapter Five recommended a policy of fully enforcing the national 70 mph (113 km/h) speed limit in order to improve vehicle fuel economy. It is recognised that a reduction in the national speed limit, to 50 or 60 mph, would lead to further improvements in fuel consumption, and probably some modal transfers to faster modes such as rail and air. However, this study proposes only the enforcement of existing limits, in line with its policy of packaging together fairly modest policy measures. Enforcing current traffic law is unlikely to meet with substantial public opposition, whereas reduced speed limits might prove highly unpopular among motorists who have become accustomed to motorway travel.

The effect on fuel consumption of a vigorous enforcement policy would be immediate. On the basis of the calculations shown in Appendix 3, it is estimated that effective enforcement, using both police patrols and automatic surveillance, would improve average car fuel economy by two per cent over a period of five years.

The effect on motorcycle fuel consumption is assumed to be negligible, since they account for less than one per cent of CO₂ emissions from personal travel. Similarly, coaches are assumed to be unaffected by this policy measure, since over three-quarters are already travelling below the speed limit.

The effect of speed limits on modal choice is uncertain. On the one hand, a reduction in car speeds can make other modes more attractive. On the other hand, the enforcement of speed limits may actually increase traffic flows by smoothing out bottlenecks. The author takes the view, based on conversations with a transport engineer, that the effect of speed on journey times is generally overestimated by drivers. The average trip length for a company car driver on business is of the order of 80 km. For an average trip, a 10mph reduction in speed lengthens the journey time by five minutes, a period of time that is hardly significant in a normal working day. The possibility of forward planning reduces still further the possible delay associated with a reduction in trip speed. On this basis, it is assumed that the modal distribution of travel would be unchanged by the full enforcement of 70 mph speed limits.

7.3.3. The urban access package

As explained above, a number of policy measures can be more successful if introduced as part of a synergistic package. Accordingly, five of the policies described at the end of Chapter Five are now assembled into an *urban access package*, containing measures similar to those deployed in Singapore. The urban access package is likely to have most influence on work-related journeys, since work trips account for the majority of city traffic, particularly in peak periods. The package consists of:

- area licensing;
- increased spending on public transport;
- employer-based travel schemes;
- business taxes to reflect accessibility;
- urban planning to reduce travel demand.

The following is an evaluation of each component of the urban access package.

AREA LICENSING

Evidence from Singapore and Milan (MTRU, 1991) provides useful guidance as to the likely effect of area licensing schemes in Britain's major cities. An increase in the capacity of public transport is an essential requirement for the success of area licensing schemes. The effective timescale for the introduction of an area licensing scheme is estimated to be five years, and the necessary expansion of public transport provision could take place over a similar period. Area licensing may also be supplemented by traffic calming schemes, and its effectiveness improved by the introduction of parking restrictions inside the designated zone.

A number of cities in Europe are currently considering the exclusion of cars altogether. A feasibility study launched by the European Commission in June 1992 suggests alternatives to car-dominated urban planning. Cities in Britain that have expressed an interest in the 'car-free cities' concept include York, Bath and Chester (Local Transport Today, 1992).

In order to evaluate the transport impacts of area licensing, it is necessary to establish what proportion of the population will be affected in major towns and cities, and what their response will be. Evidence from the 1981 Census (OPCS, 1984) indicates that in towns and cities, typically 20 per cent of the resident working population commute into the centre of large towns and cities whose size might justify area licensing. In rural areas, the figure is approximately 5 per cent. These figures represent the fraction of work journeys that would go into areas with a potential for licensing.

For shopping, personal business, social and entertainment trips, it is assumed that the proportion of trips affected is half of the equivalent fraction for work trips. This means that in urban and intermediate areas, 10 per cent of these trips would be affected by area licensing schemes, and in rural areas 2.5 per cent would be affected.

The variation in effect between different journey types is expected to occur because journeys for shopping, personal business or social and entertainment purposes are more flexible than work trips in terms of changing the destination. Many trips for shopping, personal business, social and entertainment can be transferred to other areas if necessary. By contrast, there is

little possibility for commuters to switch to a new destination in order to avoid an area licensing scheme.

Trips in the category 'holiday and other' are assumed to be unaffected by area licensing, because they tend to be longer and less scheduled.

On the basis of evidence from Milan and Singapore, it is assumed that 40 per cent of car trips affected by an area licensing scheme would be eliminated. Some of these would be avoided altogether, and others would be transferred to bus, rail and cycle. Walking is not considered to be a significant alternative in this instance, since in the present pattern of journeys very few car trips are of a length that facilitates walking. The modal split of the transferred journeys is taken to be 15 per cent to bus, 15 per cent to rail, and five per cent to cycle. The remaining five per cent of car trips are not transferred, but cancelled altogether.

As before, these changes are expressed in the SPACE model by modifying individual lines in each spreadsheet. Trip numbers, rather than lengths, are altered by the area licensing policy measure. The extent to which an individual line is affected depends on its ranking according to journey purpose and geographical area type.

Additionally, it is expected that an area licensing programme would lead to an increase in car-sharing, and a resulting rise in occupancy. Scenario 3 includes a five per cent increase in car occupancy for people living in urban and intermediate areas, taking place between 1995 and 2010.

INVESTMENT AND SUBSIDY FOR PUBLIC TRANSPORT

The second policy measure in the urban access package involves an increase in investment and revenue subsidy for public transport. Investment allows the public transport infrastructure to be expanded or improved, whereas subsidies reduce the price of travel for users.

The essence of such a policy is to facilitate a transfer from car to public transport, which would be stimulated by other elements in the package. However, transfers to public transport would also take place from walking and cycling, as a result of the reduction in fares.

Goodwin (1988) has catalogued a variety of estimates for the elasticity of public transport demand with respect to fares. His results are summarised in Table 7.1. These are set in the context of isolated measures, rather than as part of a package. It might therefore be expected that the response to fares reductions in the urban access package would be greater than these elasticities suggest.

Goodwin's results indicate that the use of public transport responds positively to reductions in fares. A 10 per cent reduction in fares, for instance, would ultimately bring about an increase of 6.5 per cent in bus use, four per cent in Tube use, and 11 per cent in rail use. These increases would take place as a result of both transfers from other modes and the generation of additional trips. Estimates of this sort are by no means precise, but the report in which they are quoted aims to summarise the best available evidence on elasticities.

Table 7.1 Elasticity of public transport demand with respect to fares

Demand	With respect to	Elasticity	
		Short term	Long term
Bus usage	Bus fares	- 0.3	- 0.65
Tube usage	Tube fares	- 0.2	- 0.4
Rail usage	Rail fares	- 0.7	- 1.1

Source: Goodwin, 1988.

At present, many public transport systems are operating at full capacity and beyond. A programme of capital investment would facilitate an expansion in capacity, thereby allowing an increased level of patronage. It should be noted that there is a degree of suppressed demand on many overcrowded transport systems. An investment in extra capacity would therefore result in increased patronage even without the additional use of fare subsidies.

In the previous section it was estimated that 40 per cent of car journeys affected by area licensing would be eliminated. These were distributed between bus trips (15 per cent), rail trips (15 per cent), cycle trips (five per cent), and cancelled journeys (five per cent). However, this pattern of changes did not take account of the modal transfer effects of reducing public transport fares.

Given that fare subsidies are an essential complement to the area licensing programme, it is likely that the use of public transport (bus and rail) would increase as a result of trip generation. In addition, there would be some modal transfers from cycle and walking to public transport, as a result of the lower cost.

Fare subsidies therefore require a careful balance to be struck, so that modal transfers from cars are promoted but the less desirable effect of trip generation is avoided. It is likely that policies would need to be 'fine-tuned' on the basis of observed changes in travel demand.

The assumptions contained in Scenario 3 recognise the trip-generating potential of subsidised fares, and are considered to be representative of the likely effect. Scenario 3 assumes that the 40 per cent of eliminated car trips would be redistributed as follows.

The five per cent increase in cycling that resulted from the area licensing schemes would be lost as a result of transfers from cycle to bus and rail. The five per cent of trips that were cancelled altogether as a result of area licensing would return, in the form of bus and rail trips. The overall result would be that the use of bus and rail would increase, with each accounting for half of the 40 per cent of eliminated car trips.

In the context of the urban access package, Goodwin's figures suggest that fares would need to fall by approximately 30 to 40 per cent in order to facilitate this transfer to public transport. This subsidy would be accompanied by an investment in expanded capacity.

EMPLOYER-BASED TRAVEL SCHEMES

The third measure in the urban access package is a programme of employer-based travel schemes aimed at reducing the use of cars. Chapter Five described schemes whereby employers could encourage their staff to reduce the energy consumption of their commuting journeys. Practices included car-sharing, bus provision and telecommuting. A policy aimed at establishing similar schemes in Britain would be a long-term undertaking, although some results would begin to be seen fairly quickly.

Incentives for car-pooling could reduce car mileage relatively rapidly, whereas measures aimed at providing mass transit and promoting teleworking would take longer to implement. One of the hazards of a car-pooling policy is that it may simply attract public transport users into cars, which in most cases would have a negative rather than a positive influence on energy consumption. This can be addressed by deploying car pooling schemes as part of a package of measures that promotes public transport. The urban access package aims to provide such a strategic approach.

There is little or no experience of car pooling schemes in Britain. However, a number of demonstration schemes have been established in the USA, with widespread success. A summary of pilot projects initiated by employers in California is provided by Collier (1991). Although the historical data do not extend earlier than 1989, they demonstrate a definite trend away from single-occupant car trips and towards shared cars and public transport. The results are summarised in Table 7.2.

It should be noted that these results were achieved in a climate of very cheap fuel, together with an infrastructure that is highly car-oriented. Conditions in Britain are likely to be considerably more conducive to modal transfer than those in California. On this basis, it is expected that five per cent of work journeys by car could be eliminated after five years as a result of car-pooling measures, rising to 10 per cent of journeys after 15 years as additional measures are implemented.

Table 7.2 Travel modes of commuters in southern California

Mode	Percentage		
	1989	1990	1991
Drive alone	83	79	78
Carpool	11	14	14
Vanpool	0	1	1
Bicycle	2	1	1
Motorcycle	1	0	0
Public bus	2	4	5
Private bus	0	1	0
Walk or jog	1	1	1
Commuter rail	n/a	n/a	0

n/a = not asked.

Source: Collier, 1991.

The reduction in car trips would bring about a corresponding increase of five to 10 per cent in the work-related mileage of bus and rail. Between 2010 and 2025, an additional five per cent of car trips are eliminated altogether as telecommuting becomes available for some employees. On the basis of experience gained in California, car occupancy is expected to increase for people living in urban and intermediate areas, by five per cent over the period up to 2000.

BUSINESS TAXES TO REFLECT ACCESSIBILITY

In the absence of empirical evidence, the effect of access-related business taxes is difficult to predict. In qualitative terms, the likely result would be a transfer of business premises closer to residential areas and urban centres, and a reduction in the length of work journeys. In

addition, it is probable that some shopping and personal business trips would also be shortened.

A typical business might at some point decide to move from an out-of-town site to a location within the boundary of the nearest town. This would reduce the length of the commuting trip for employees based in the town, although other workers (such as those living in rural areas) might need to travel further. In the longer term, the workforce would begin to be drawn increasingly from the environs of the new premises. Thus although the short-term effect on travel demand is hard to judge, in the longer term the firm's employees would consist increasingly of more local residents. The same effect applies to shopping journeys.

For a particular town, a reduction in the length of commuting trips by an average of 20 per cent appears to be an achievable target for such a policy as part of the urban access package. Shopping and personal business trips are assumed to be shortened by half this amount, since fewer journeys are involved in this category. Such a reduction in journey length would allow a proportion of car trips to be transferred to public and non-motorised modes of transport, including walking. A reasonable estimate is that 10 per cent of commuting journeys by car would change to other modes including walking and cycling. The timescale for full implementation is assumed to be 30 years, since relocation of existing businesses (and turnover of staff) cannot be expected to take place other than as part of long-term business relocation decisions.

URBAN PLANNING TO REDUCE TRAVEL DEMAND

Chapter Five has documented the relationship between urban form and travel-related energy consumption. Work carried out by Steadman and Barrett (1991) suggests two types of urban form that might reduce the need for travel. The first is a concentrated, centralised city structure, and the second is an arrangement of small local centres or 'villages' (Figure 5.4).

A transfer to these types of layout could be achieved by central government working through the local government planning system. To a large extent, a transfer to walking and cycling would be expected to follow naturally from any reduction in land-use dispersal, though it could be further encouraged by improvements in the facilities for these modes. At present, safety is a major deterrent to cycling in Britain, and it is likely that improvements in junction design, together with the creation of dedicated cycle lanes, could encourage a significant number of car users to transfer to non-motorised travel for local trips.

The fifth and final element the urban access package involves the implementation of planning regulations for improved access and reduced travel demand. This policy would affect the location of homes, businesses, shops, services and so on as well as the introduction of new schemes such as traffic calming, pedestrianisation and revised car-parking arrangements. Of

all the policies, this has the longest timescale. It is not realistic to suppose that changes in land-use planning could achieve their full potential within the timescale of the SPACE model, which extends to 2025. Nevertheless, there will be a substantial number of new developments taking place in this period, many of which could be revised in order to emphasise access rather than mobility.

The benefit will be a very gradual one, and will tend to affect trip length rather than the number of trips (Owens, 1986). There will also be a concomitant transfer away from cars to public and non-motorised travel modes, which itself would tend to reduce trip lengths. The effect would take place across all types of journey, with the exception of leisure and long-distance trips.

This policy measure is complementary to the four other components of the urban access package, and this study does not attempt to evaluate its effect in isolation. In addition, the timescale of the SPACE model is insufficient to gauge the full effect of this policy. Rather, land-use planning is viewed as a general strategy that should be adopted in order for other measures, such as area licensing and public transport investment, to succeed. It will also increase the likelihood that reductions in CO₂ emissions from personal travel can be sustained beyond 2025 and throughout the next century.

Up to this point it has been fairly straightforward to estimate the effect of the various policy measures deployed, subject to a reasonable degree of uncertainty. The remaining policy measure, which involves a review of the way in which inter-urban road and rail schemes are assessed, is more difficult to evaluate. To some extent it is a means to achieve the other policies, by building travel targets into the planning of transport infrastructure. This process itself affects the future level of travel demand.

7.3.4. The environmental assessment of roadbuilding schemes

The measures contained in the urban access package are all concerned with travel in urban areas, although they will have some influence on inter-urban trips. The final policy measure in Scenario 3 concerns inter-urban travel, and in particular the way in which different modes are considered by the Department of Transport during the transport planning process.

Government figures (Department of Transport, 1991a) indicate that traffic growth in recent years has taken place mainly on inter-urban routes. In the decade to 1990, traffic on motorways and non built-up major routes grew by 73 per cent, whilst that on built-up major routes grew by just 20 per cent. Although the public perception of growing traffic problems tends to focus on towns and cities, where the effects of congestion are most noticeable, a major growth in CO₂ emissions is likely to take place outside urban areas under a business-as-usual scenario.

The Government's trunk roads programme involves an expansion of the capacity of Britain's roads, based on a projected growth in road traffic (see Chapter Four). Scenario 1 has shown that the substantial increase in CO₂ emissions that will result from this 'business as usual' growth is incompatible with a national strategy for reducing emissions. However, a limited growth in traffic volume may be compatible with a CO₂ reduction strategy.

The Department of Transport's White Paper *Roads for Prosperity* (Department of Transport, 1989b) outlines the Government's commitment to roadbuilding, and gives details of an expanded trunk road programme for Britain. The paper states that '...the main way to deal with growing and forecast inter-urban road congestion is by widening existing roads and building new roads in a greatly expanded road programme.'

However, there exists a counter-argument to this view, which states that building roads tends to increase the demand for roadspace, and in some cases leads to worse congestion. This was recently expressed by the European Commission in its Green Paper on transport and the environment, which states that 'If there is congestion, planning should not necessarily seek to increase the road network, because this can lead to an increase in demand' (European Commission, 1992).

Potter (1992b) points out that the majority of the Government's roadbuilding programme involves an expansion in the capacity of Britain's roads. On the basis that increased capacity leads to increased demand, it is reasonable to expect that a reduced budget for roadbuilding would lead to a reduced growth in road traffic. Coupled with an increase in government spending on public and non-motorised modes, a modal transfer to rail and interurban coach travel could be achieved.

How the growth in traffic would be constrained would depend on what other policies are adopted. In the absence of other policies, traffic levels would be held down by increasing levels of congestion - though this option is not regarded as a valid transport policy in itself. Alternatively, an investment in public transport could facilitate a transfer from car to other modes of travel.

The list of measures proposed at the end of Chapter Five included a system of environmental assessment for road schemes, and a transfer of capital from cancelled roadbuilding schemes into public and non-motorised modes of transport. The objective was to achieve a modal transfer away from cars.

The Royal Town Planning Institute (1991) recommends that environmental considerations be included in the appraisal of new road schemes. 'The application of consistent mechanisms of assessment in economic, social and environmental terms to all transport proposals, together with an opportunity for review by an independent body, is an objective that should command wide support.'

Transport consultants Steer, Davies and Gleave have recently assessed the feasibility of transferring capital from the proposed M1 motorway widening scheme to the electrification of British Rail's London to Sheffield main line. They estimated that patronage of the line could double over the next 20 years, with 60 per cent of the new passengers switching from car. By using the cost-benefit analysis method currently associated with road appraisal, the consultants showed that the financial benefits of the scheme were ten times greater than if the conventional appraisal method for rail projects had been used (Black, 1992).

The final component of Scenario 3 is the establishment of a common appraisal system for road and rail schemes, which takes into account the level of CO₂ emissions from all the alternative transport options under consideration. It is impossible to predict what proportion of road projects might be cancelled in favour of less carbon-intensive travel modes, and therefore the volume of capital that would be available for investment in other modes. However, in the example of the M1 motorway above, the result of transferring capital from road to rail investment is a six per cent transfer of traffic from motorway to rail as a result of the improved rail service. If such a strategy were to take place at a national level, then the modal transfer would be likely to be greater than this because of 'network' effects and changes in travel behaviour. The effect would be twofold: existing journeys would be transferred to rail from road, and the future growth in car traffic would be diminished.

The urban access package has affected mainly journeys to work, since these account for a large proportion of traffic in urban areas. In contrast, a policy aimed at altering the balance between road and rail investment would affect longer-distance trips, such as those undertaken in the course of work and for holidays, social visits and personal business.

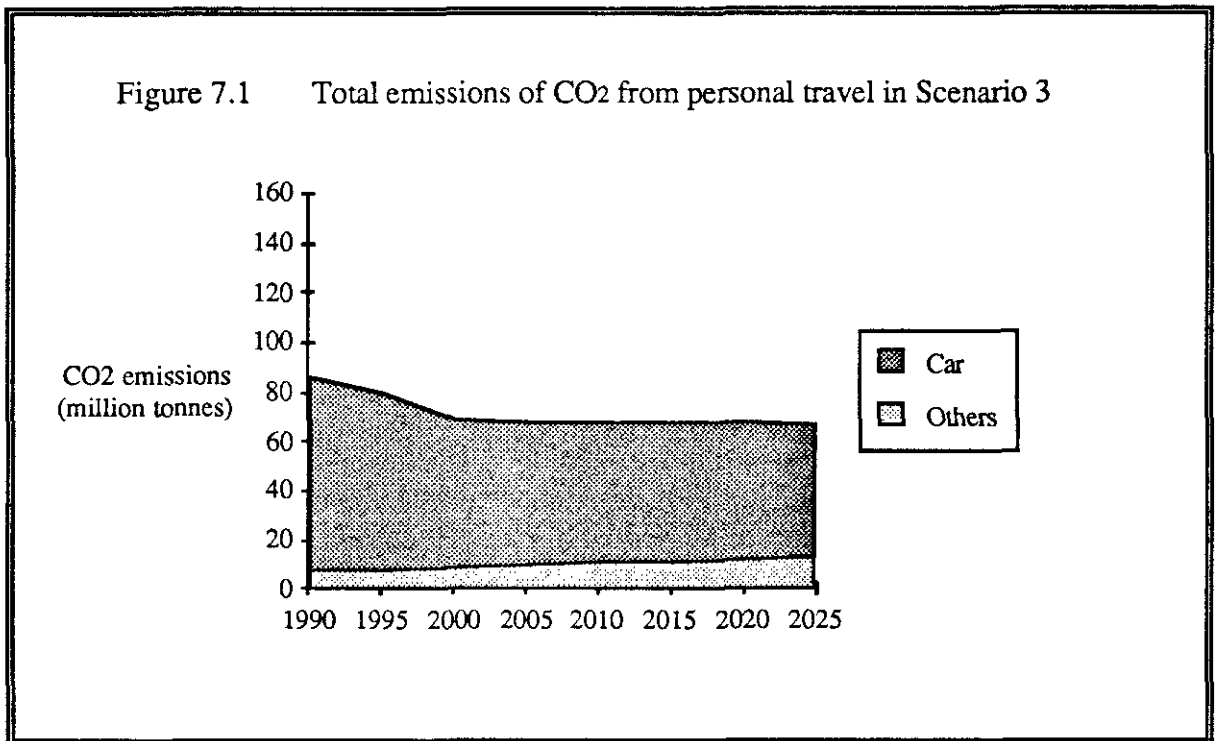
On the basis of the M1 example, Scenario 3 assumes a 20 per cent reduction in car traffic growth up to the year 2025, of which half is transferred to rail. The reduction is expected to take place for all journey types. However, the modal transfer to rail is not expected to take place among rural dwellers, because they are unlikely to have access to inter-city rail stations.

In addition, the expansion of interurban rail capacity, including the introduction of new high-speed lines, would be likely to attract a modal transfer from air to rail. Scenario 3 assumes a 20 per cent transfer of passenger kilometres from domestic air services to high-speed rail, over a period of 20 years. However, a policy of expanding interurban high-speed rail would need to be monitored carefully, because airline companies might be tempted to run rail services as an alternative to flights as part of a policy to liberate valuable airspace. In such a scenario, the net result would be an increase in rail travel with no accompanying reduction in air travel.

7.4. Constructing a stabilisation scenario

Having evaluated all the policy measures proposed in Chapter Five, it is now possible to construct the third and final scenario. The objective is to provide a strategy by which emissions of CO₂ from personal travel may be reduced by 20 to 25 per cent as part of a broader goal of atmospheric stabilisation.

Figure 7.1 shows the effect of Scenario 3 in terms of CO₂ emissions. Total CO₂ production from personal travel is reduced by 22 per cent, with the majority of the reduction taking place up to the year 2000. After 2000, the main effect of the policy changes is to counteract a continued, though reduced, increase in road traffic.

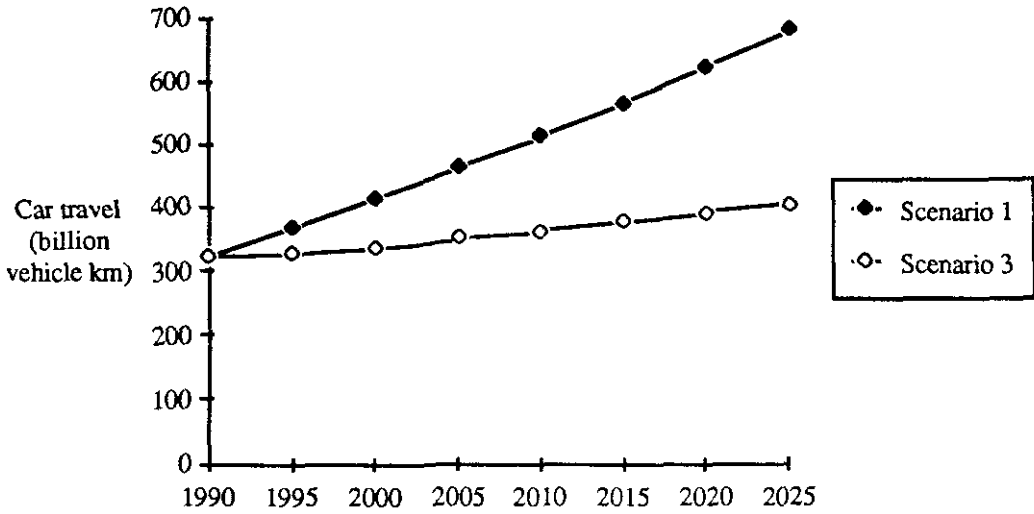


These results suggest that **Scenario 3 offers a means by which personal travel may contribute to a strategy for stabilising the atmospheric concentration of CO₂**. Greater reductions would be required in other sectors, as in the German model described in Chapter Five.

It is worth noting that the effects of the measures introduced so far in Scenario 3 have been estimated conservatively. For example, the use of elasticities has not taken into account the synergistic effect associated with the packaging of policy measures. On this basis, Figure 7.1 may underestimate the potential for reducing emissions.

It is useful to know what the aggregate effect on demand for different modes has been. Figure 7.2 compares the business-as-usual growth in car traffic with that associated with Scenario 3 so far.

Figure 7.2 The effect on car traffic growth of Scenario 3 measures



The 22 per cent reduction in CO₂ emissions is achieved at the same time as a modest growth in car traffic - 16 per cent over the period 1990 to 2025. In the same period, rail grows by 87 per cent, bus by 31 per cent and cycling by five per cent, while walking declines by 33 per cent.

Chapter Eight

CONCLUSIONS

8. CONCLUSIONS

“We are at the very beginning of time for the human race. It is not unreasonable that we grapple with problems. But there are tens of thousands of years in the future. Our responsibility is to do what we can, learn what we can, improve the solutions, and pass them on. It is our responsibility to leave the people of the future a free hand.”

- Richard Feynman, ‘The Value of Science’

This study was prompted by an awareness that transport is a significant, and growing, contributor to emissions of ‘greenhouse’ gases in Britain. During the three years spent undertaking this work, the British government has formally acknowledged the reality of the global warming threat and the need to take precautionary action. It is hoped that the conclusions of this research will help to establish policies aimed at marrying the provision of transport with the protection of the global environment. To this end, results from this project have been submitted to the Royal Commission on Environmental Pollution, which is currently undertaking a study of pollution from the transport sector. In addition, a number of papers and articles have been published during the course of the work (see Appendix 5).

8.1. Principal findings

Scientific opinion strongly favours the hypothesis that human activities are beginning to change the climate through global warming. Although the evidence is currently inconclusive, climate measurements are broadly consistent with the view that a significant warming trend has begun. The need to find ways of curbing greenhouse emissions is likely to become greater, not less, as the warming trend emerges. The most comprehensive survey of the science of global warming is that done by the IPCC scientific working group, as described in Chapter One, which proposes an immediate reduction of 60 per cent in CO₂ emissions in order to stabilise the atmospheric concentration of this gas and to minimise the global warming effect.

Passenger transport is a major contributor to CO₂ emissions in Britain, and its significance will increase as the demand for travel continues to rise. A 'business as usual' scenario, as examined in Chapter Four, implies a near-doubling of CO₂ emissions from the transport sector. To date, the Government has not put forward any means by which such an increase in CO₂ production may be reconciled with its target for stabilising emissions overall.

In the transport sector, there are many options available for breaking the upward trend in CO₂ emissions. These may be broadly categorised into technological changes and alterations in the demand for travel. In Scenario 2 (Chapter Six), a modification of 'business as usual', in which technological improvements are applied to new cars in Britain, demonstrates the limitations of technology-based solutions. A combination of fuel economy incentives and an alternative fuels programme leads to a reduction in the rate at which emissions rise. But the total output of CO₂ in the 'technical fixes' scenario is still 35 per cent higher in 2025 than it was in 1990.

It is therefore necessary to look beyond technological changes in order to achieve a reduction in CO₂ emissions from personal travel. A variety of policies are available for influencing the volume and modal distribution of travel. Some of these are measures that have been used in the past for other purposes, such as the subsidisation of public transport. Others are virtually unprecedented, such as the European Commission's proposed energy tax.

An important finding of this study is that technological changes offer only a limited potential for curbing emissions, and that a successful strategy for reducing CO₂ emissions from personal travel must focus on ways of reducing the demand for travel. This does not automatically imply the use of 'trip suppression' measures, but rather a promotion of lifestyles that do not require the level of mobility upon which society is presently dependent. Like energy, transport is rarely something that people value in itself; more commonly, it is a means of gaining access to people, goods and services.

By combining a number of policy measures together into a third, 'modified travel demand' scenario, it is possible to estimate the combined effect on CO₂ emissions of technological changes plus policies to moderate the demand for travel. Scenario 3 (Chapter Seven) indicates that such a strategy could reduce CO₂ emissions from travel by 22 per cent. A number of the policies contained in this scenario are deployed in the form of a 'package', in order to exploit their complementary effect on one another.

8.2. Implications for an overall CO₂ reduction strategy

Some of the elements contained in the final scenario are, to some degree, speculative, and the 22 per cent reduction in emissions that the SPACE model predicts should not be regarded as a representation of the greatest reduction in emissions that is possible. Rather, it is the

best estimate of the aggregate effect of the twelve policy measures proposed. Without the benefit of real-life experience, there is inevitably a degree of uncertainty surrounding the potential for reducing greenhouse emissions.

If it is assumed that personal travel would be allocated a target less stringent than those for other energy sectors, it appears possible for Britain to achieve a substantial reduction in CO₂ emissions across all sectors. The question of allocating sectoral targets is difficult and requires further research, but some work has been undertaken to this end in Germany (see 5.1). As part of an overall 25 per cent reduction in CO₂ emissions, the transport sector was apportioned a target of nine per cent.

If the same ratio were applied to the 22 per cent reduction in emissions projected for passenger transport in Scenario 3, it would imply an *overall* reduction in emissions of 61 per cent. Significantly, this corresponds almost exactly to the IPCC 'stabilisation' target of 60 per cent overall. The conclusion to be drawn from these speculative calculations is that **the maximum possible reduction in CO₂ emissions identified in this study is consistent with the IPCC target of 'atmospheric stabilisation'**.

8.3. Comparison with the Netherlands National Transport Plan

The best test for such a set of projections would be comparison with real-life experience. Although the historical use of environmental targets for the transport sector is extremely limited, an example of such a strategy may be found in the Netherlands National Transport Plan, adopted by the Dutch government in 1990. The *Tweed Structuurschema Verkeer en Vervoer*, or SVV2+, differs from previous transport plans in that it includes measures to curb the projected growth in car travel. The issue of global warming is addressed by a national target to hold total CO₂ emissions down to 1986 levels by the year 2000 and beyond (Sturt, 1992).

A business-as-usual scenario for car travel in the Netherlands, as presented in SVV2+, anticipates a 70 per cent growth in car mileage between 1986 and 2010. The document states that this hypothetical growth will, in reality, be constrained by the national pollution targets, as well as financial and spatial limitations. As a result, it is suggested that the overall growth up to 2010 be halved to 35 per cent (*ibid*). For comparison, Scenario 3 in this study envisages a 14 per cent growth in car traffic between 1988 and 2010 (see Figure 7.3).

There are clear parallels between the Dutch approach and the ideas developed in this thesis. Technological measures are, in both cases, viewed as inadequate to achieve CO₂ abatement targets, and ways are sought to constrain the projected increase in travel demand.

The Dutch policy plan proposes measures that might be deployed with this goal in mind. These include sharp increases in fuel taxes and major infrastructure investment for public transport. Plans to expand the Dutch rail network are already under way, with a target of doubling the capacity of the infrastructure. Likewise, the final scenario of this study proposes a large-scale expansion of rail capacity for inter-urban trips, in order to achieve a substantial modal shift away from car travel.

The Dutch plan also draws heavily on land-use policies to help limit the growth in car travel. Future employment centres would be classified according to the nature of their transport links, and different types of activity assigned to appropriate areas. However, the shortcomings of such a policy were sharply illustrated at the beginning of 1992, when the multinational electronics company Toshiba abandoned plans to locate its European head office in the Netherlands because of what it saw as excessive restrictions on development (ibid). Unless development restraint is established on a Europe-wide basis, it is possible that individual governments will be placed at an economic disadvantage by adopting it.

The Dutch programme, although differing in fine detail from the strategy developed in Scenario 3, has much in common with it. It demonstrates that many of the policy measures identified by this study are entirely feasible as part of a strategy for curbing motorised travel.

8.4. Non-operational emissions of CO₂

Substantial quantities of CO₂ and other greenhouse gases are produced not only in the operation of transport, but also in peripheral activities such as manufacturing and maintaining vehicles and infrastructure. This study has given some attention to the emissions produced by these secondary sources, but has not included them in the three scenario projections because primary fuel consumption for transport operations represents the majority of energy use in this sector. To undertake a detailed investigation of secondary sources would have diverted resources from the main study.

However, it is possible to make a number of observations about the future level of these secondary emissions. Firstly, the scope for reducing emissions from these sources lies largely outside the transport sector, in the electricity supply industry. A large-scale transfer away from coal to less carbon-intensive sources of electricity would reduce the level of greenhouse emissions from 'secondary', transport-related processes.

Secondly, it appears unlikely that the demand for these processes could be curbed other than as a result of a reduction in travel demand. In particular, the energy and resources required for car production and road maintenance would be likely to decrease if there were a reduction in the number of car miles travelled, and in the turnover of the car stock.

8.5. Beyond 2025

It should be noted that the three scenarios in this study all run to the year 2025, and take no account of trends that might prevail after that year. It is likely that reductions in CO₂ emissions could continue beyond 2025 if renewable energy were to increase its role in personal travel, and if land-use planning continued to embrace an access-led approach. However, such progress would depend critically on the groundwork done in the period leading up to 2025.

The ultimate potential of alternative fuels for eliminating travel-related greenhouse emissions depends heavily on national energy policy. A programme to develop renewable power sources, in the form of wind, wave, tidal and hydroelectric energy, would facilitate a large-scale transfer from petroleum to renewables in the transport sector. If global warming does not prompt a widespread move away from fossil fuels, it seems likely that supply shortages will eventually force such a change.

It is essential to guard against the idea that alternative fuels and land-use planning are the only useful measures in terms of reducing CO₂ emissions. Their potential to reduce emissions beyond 2025 depends on the reductions that might be achieved up to that year, using the 12 policies proposed in the final scenario.

Equally important is the need to adopt both short-term and long-term policies as a matter of urgency. Longer-term measures require extended lead times, and short-term measures may be regarded as 'buying time' whilst a long-range strategy is implemented.

8.6. Which way now?

At the time of writing, transport policy in Britain is undergoing major changes, particularly in the way that investment for different modes is assessed by central government. Street-running trams have returned to Manchester, and more are expected soon in Sheffield, with plans for a line in Birmingham well advanced. The SACTRA report (Department of Transport, 1992) has outlined ways in which environmental protection may be built into the trunk road appraisal process, and the Departments of Transport and the Environment have begun to examine the role of land-use planning in reducing the need for motorised travel. In addition, the Department of Transport has agreed, for the first time, to consider 'package' bids from local highway authorities, whereby a portion of their annual Transport Supplementary Grant is awarded not to individual authorities but on a region-wide basis. This would allow local authorities to collaborate on large-scale public transport projects.

To some extent the new emphasis on public transport and land-use planning is the result of a realisation that sustained traffic growth is incompatible with environmental protection goals,

as well as with the efficient running of towns and cities. The European Commission should take some of the credit for bringing environmental considerations into the national transport policies of member states. Its green paper on sustainable mobility (European Commission, 1992) cautions against using roadbuilding as a means to ease traffic congestion. "If there is congestion, planning should not necessarily seek to increase the road network, because this can lead to an increase in demand," it states.

However, the response of the British government to the issue of climate change has been characterised by strong words but little action. The 'new realism', based on the idea that roadbuilding is an inappropriate instrument for dealing with problems of congestion and pollution, contrasts strongly with the view traditionally held by the Department of Transport, which commonly cites environmental protection as a *justification* for building more roads. For example, many elements of the DTp's roadbuilding programme are presented as bypass projects, for which reductions in CO₂ emissions are claimed as one of the benefits, with no reference to the likely traffic-generating effect of increased road capacity.

In 1991, the appointment of Malcolm Rifkind as Secretary of State for Transport was seen by many as heralding an increased recognition of the value of public transport. But subsequent investment decisions have dampened hopes of a 'rail revival' or other moves away from a demand-led approach. For example, in June 1992 transport secretary John MacGregor announced that no funding would be available in 1993/4 for the planned Midland Metro LRT scheme, or for any other light rail schemes that were not already under construction, because of pressures on Department of Transport funds. The estimated cost of Line One in Birmingham was £100m. Just a few weeks later, the DTp announced plans to widen a 12 km section of the M25 motorway to 14 lanes, at a cost of £140m. This represented the first phase of a £2bn upgrading programme for the whole motorway.

While funding is being cut back for light rail investment, and parts of British Rail are in desperate need of modernisation, traditional demand-based principles have enabled the Government to raise vast amounts of money for roadbuilding projects, whose environmental impact will undoubtedly be negative.

Thus the acceptance of environmental thinking by the Department of Transport is, at best, tentative, and there is so far little evidence of it filtering through into action. Britain's goal of stabilising CO₂ emissions by the year 2000 falls well short of the 60 per cent cut proposed by the IPCC, and implies a further increase in the atmospheric concentration of this gas.

8.7. A 'do nothing' world?

The easiest response to a problem as great as climatic change is to ignore it, and hope that it goes away. This study has shown that the global warming threat is almost certain to become more severe in a 'do-nothing' world. Even if anthropogenic greenhouse emissions were to cease immediately, global temperature and sea level would be likely to rise as a result of the greenhouse 'commitment' that has already been made. More importantly, this research has demonstrated that measures are available which, based on real-life experience, are capable of bringing passenger transport into line with an 'atmospheric stabilisation' policy.

A sustainable transport strategy will need to be introduced with the utmost care in order to minimise disruption to the national economy. In particular, ways must be found of redeploing the massive resources that are at present involved in the motor and oil industries, which currently provide much of Britain's wealth.

Paradoxically, the sheer enormity of the global warming threat has tended to discourage politicians from attempting to find solutions to it. The report of the IPCC Working Group 1 has provided a sound scientific foundation upon which to base future policies. It is the responsibility of all governments to address the climate issue with a sense of vision and urgency. The uncertainty that continues to pervade climate forecasting has provided a rationale for 'no regrets' policies, which will produce a net benefit to society even if the greenhouse threat eventually turns out to have been overestimated. Many of the measures proposed in this study are regarded as 'no regrets' policies.

In Britain's history, there have been numerous threats to peace and stability. Many of these were overcome through a combination of strong government backed up by a highly motivated populace. Today, global warming threatens our security on a global, rather than a regional, scale. A similar degree of commitment and leadership will be needed from Britain, in partnership with the rest of the world, in order to avert a climatic catastrophe.

"We must not allow uncertainty to inhibit us from taking action when the needs demand it. Precautionary action should be taken in the face of uncertainty when effects are irreversible or the risks of disaster too high."

- The Rt Hon. Chris Patten MP, 5 December 1989

REFERENCES

REFERENCES

- Adams J (1990) 'Car ownership forecasting: pull the ladder up, or climb back down?' *Traffic Engineering + Control*, March, pp.136-171.
- Alexander W and Street A (1989) *Metals in the Service of Man* ninth edition, Penguin.
- Banister C and Banister D (1991) Personal communication.
- Barrett S (1991) 'Global Warming: Economics of a Carbon Tax' in Pearce D, ed (1991) *Blueprint 2* Earthscan, London.
- Barrie C (1990) 'VW "flask" keeps the heat on when the engine's off' *The Engineer* 5 April.
- Black D (1992) 'Councils want M1 cash to update rail line' *The Independent* 11 January.
- Boehmer-Christiansen S (1990) 'Vehicle Emission Regulation in Europe - the demise of lean-burn engines, the polluter pays principle... and the small car?' *Energy and Environment* Vol 1 No 1, pp.1-25.
- Boyle S (1989) *Solutions to Global Warming* Association for the Conservation of Energy, London.
- BBC Radio Four (1991) *Going Places* 29 November.
- British Rail (1991) *InterCity File*.
- Cairncross F (1991) *Costing the Earth* Business Books, London.
- Carr G (1983) 'Potential for Aerodynamic Drag Reduction in Car Design' *International Journal of Vehicle Design*, Technological Advances in Vehicle Design Series, SP3, 'Impact of Aerodynamics on Vehicle Design', pp.44-56.
- Champion (1987a) 'Recent Changes in the Pace of Population Deconcentration in Britain' *Geoforum* Vol 18, No 4, pp.379-401.
- Champion (1987b) 'Momentous revival in London's population' *Town & Country Planning* Vol 56 No 3, pp.80-82.
- Champion (1990) Personal communication.

Chang T, Hammerle R, Japar S and Salmeen I (1991) 'Alternative Transportation Fuels and Air Quality', *Environmental Science and Technology* Vol 25, No 7, pp.1190-1197.

Collier C (1991) 'Trip Reduction Strategies: Will Commuters Change Travel Behaviour?' Transportation and Global Climate Change: Long-Run Options, Pacific Grove, California, 25-28 August.

Cookson C (1989) 'A Last Chance for the Atmosphere' *Financial Times*, 6 March.

Corrado M (1990) 'Green Transport and the Consumer' presented to the conference 'Environment Policy in Local Transport', 27 March, London.

Cousins S (1984) *Opportunities for automobile fuel economy arising from new technology and design* Energy and Environment Research Unit, Open University.

Dallemagne D (1990) *An Assessment of Potential Alternative Fuels for Vehicles in Europe* MSc dissertation, Imperial College Centre for Environmental Technology, London.

Davies C (1991) 'Environmental locomotives' *Modern Railways* January, p.45.

Department of Energy (1981) *Prospects for improved fuel economy and fuel flexibility in road vehicles*, Energy Paper 45, HMSO, London.

Department of Energy (1984) *Energy Use and Energy Efficiency in UK Manufacturing Industry up to the year 2000, Volume I* HMSO, London.

Department of Energy (1989) *Energy Use and Energy Efficiency in UK Transport Up to the Year 2010* HMSO, London.

Department of Energy (1990) *An Evaluation of Energy-Related Greenhouse Gas Emissions and Measures to Ameliorate Them*, Energy Paper 58, HMSO, London.

Department of Energy (1991) *Digest of UK Energy Statistics* HMSO, London.

Department of Transport (1988) *National Travel Survey: 1985/86 Report - Part 1*, HMSO, London.

Department of Transport (1989a) *National Road Traffic Forecasts (Great Britain)* HMSO, London.

Department of Transport (1989b) *Roads for Prosperity* HMSO, London.

Department of Transport (1990) *New Car Fuel Consumption - The Official Figures* HMSO, London.

Department of Transport (1991a) *Transport Statistics Great Britain* HMSO, London.

Department of Transport (1991b) 'Automatic vehicle speed data' *Road Accidents Great Britain 1990* HMSO, London.

Department of Transport (1992) *Assessing the Environmental Impact of Road Schemes* HMSO, London.

Dix M and Goodwin P (1982) 'Petrol prices and car use: a synthesis of conflicting evidence' *Transport Policy Decision Making* 2, pp.179-195.

Dobson A, Jolly A and Rubenstein D (1989) 'The Greenhouse Effect and Biological Diversity' *Trends in Ecology and Evolution* Vol 4 No 3, pp.64-68.

The Economist (1990) 'Japan's minicar market' 10 March.

Edmonds J and Reilly J (1983) 'Global energy and CO₂ to the Year 2050' *Energy Journal* Vol 4, No 3, pp.21-47.

The European Commission (1992) *Green Paper on the Impact of Transport on the Environment: Sustainable Mobility* February, Brussels.

Fagan M (1989) 'Europe "could curb emissions of CO₂ cheaply by 2005"' *The Independent* 29 October.

Faux R (1991) 'New streetcars of desirability' *The Times* 1 July, London.

Fergusson M (1990) *Subsidised Pollution: Company cars and the Greenhouse Effect* Greenpeace UK.

Fergusson M and Holman C (1990) *Atmospheric Emissions from the Use of Transport in the United Kingdom Volume Two: The Effect of Alternative Transport Policies* WWF, England.

Fisher D, Hales C, Wang W-C, Ko M and Sze N (1990) 'Model calculations of the relative effects of CFCs and their replacements on global warming' *Nature* Vol 344 No 6266, pp.513-516.

Gardner D (1991) 'EC energy tax moves a stage closer' *Financial Times* 14 December.

Gawthorpe R (1983) 'Train drag reduction from simple design changes' *International Journal of Vehicle Design*, op cit, pp.342-353.

GEC Autoguide (1990) Publicity material.

Gooding K (1991) 'Quantum leap from cans to cars' *Financial Times*, London, 21 June.

Goodwin P (1988) *Evidence on Car and Public Transport Demand Elasticities* Transport Studies Group, University of Oxford.

Goodwin P (1991) *Managing Traffic to Reduce Environmental Damage* Transport Studies Group, University of Oxford.

Goodwin P, Hallett S, Kenny F and Stokes G (1991) *Transport: The New Realism* Transport Studies Unit, University of Oxford.

Gotz H (1983) 'Bus design features and their aerodynamic effects' *International Journal of Vehicle Design*, op cit, pp.229-255.

Greene D (1989) 'CAFE OR PRICE?: An analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978-89' *The Energy Journal* Vol 11, No 3, pp.37-57.

Gribbin J (1989) 'The end of the ice ages?' *New Scientist* No 1669. pp.48-52.

Haines A (1990) 'The Implications for Health', in Leggett J , ed (1990) *Global Warming: The Greenpeace Report*, Oxford University Press.

Hall D (1991) 'Altogether misguided and dangerous' *Town & Country Planning* Vol 60, No 11/12, pp.350-351.

Hamer M (1979) *Striking a Spark* Transport 2000, London.

Hammond A, Rodenburg E and Moomaw W (1991) 'Calculating National Accountability for Climate Change' *Environment* Vol 33 No 1, pp.10-35.

Hass-Klau C (1990) 'Greening the streets with public transport' *Urban Transport International* May/June, Landor, London.

Heaps C (1991) 'The Networker Revolution' in *Network 2000*, a *Rail* supplement.

Highfield R (1989) 'Global warming melts polar ice at British Antarctic base' *Daily Telegraph*, 27 September.

Hoffman G and Zimdahl W (1988) 'Recommended speed indication within the vehicle - a contribution to fuel saving through the "Wolfsburg Wave" information system' presented to the conference *Energy Efficiency in Land Transport*, Luxemburg, Commission of the European Communities.

Holman C, Fergusson M and Robertson T (1990) *The Route Ahead: Vehicle Pollution* WWF, London.

- Houghton J, Jenkins G and Ephraums J, eds (1990) *Climate Change: The IPCC Scientific Assessment* Cambridge University Press.
- House of Commons Energy Committee (1991) *Government Observations on the Third Report from the Committee (Session 1990-91) on Energy Efficiency* HMSO, London.
- House of Lords Select Committee on the European Communities (1991) *Energy and the Environment* HMSO, London.
- Howard D (1990) *Energy, Transport and the Environment*, Transnet, London.
- Hughes P (1990) 'Transport and Pollution: What's the Damage?' presented to the conference 'Environmental Policy in Local Transport', 27 March.
- Hughes P (1991) 'Exhausting the Atmosphere' *Town & Country Planning* Vol 60 No 9, pp.267-269.
- Jackson T and Schoon N (1991) 'There's something electric in the air' *The Independent* 2 September.
- Kelly M (1990) 'Halting Global Warming', in Leggett J, ed (1990) op. cit.
- Knight A and Cooke J (1985) *Alternatives to Petrol* Standing Conference on Schools' Science and Technology.
- The Labour Party (1990) *Moving Britain into the 1990s: Labour's new programme for transport*.
- Lashof D and Tirpak D (1989) *Policy options for stabilizing global climate* USA Environmental Protection Agency.
- Laughren F (1991) Statement to the Legislature on Tax on Fuel Inefficient Vehicles, 24 June, Ontario.
- Leggett J (1990) 'The Nature of the Greenhouse Threat', in Leggett J, ed (1990) op. cit.
- Leone R and Parkinson T (1990) *Conserving Energy: Is There a Better Way? A study of corporate average fuel economy regulation* Boston University.
- Levenson L and Gordon D (1990) 'Drive +: promoting cleaner and more efficient motor vehicles through a self-financing system of state sales tax incentives' *Journal of Policy Analysis and Management* Vol 9 No 3, pp.409-415.
- Liberati A (1991) Personal communication, Agip, Rome.

- Local Transport Today (1991) 'DTp opens door to new approach to traffic forecasting' No 49, p.1.
- Local Transport Today (1992) 'York volunteers for European "car free city" club' No 84, p.1.
- MacKinnon I (1991) 'Londoners in favour of peak-time road fees' *The Independent* 27 September.
- Maltby D, Monteath I and Lawler K (1978) 'The UK surface passenger transport sector: energy consumption and policy options for conservation' *Energy Policy* Vol 6 No 4, pp294-313.
- Markandya A (1991) 'Global Warming: The Economics of Tradeable Permits' in Pearce D (ed), op. cit.
- MORI (1990) *Public Attitudes Towards Transport and Pollution* WWF, London.
- Marshall J (1991) 'How Fuel Efficiency May Backfire' *San Francisco Chronicle* 28 July.
- Metropolitan Transport Research Unit (1990) *Accessibility and Mobility: towards a useful measure of movement benefits* Discussion paper.
- Metropolitan Transport Research Unit (1991) *Traffic Restraint: Five Cities, Five Solutions* London.
- Mills E, Wilson D and Johansson T (1991) 'Getting started: no-regrets strategies for reducing greenhouse gas emissions' *Energy Policy* Vol 19 No 6 pp.526-542
- Milne R (1990) 'CFC clampdown eases pressure on the ozone layer' *New Scientist* No 1724, p.21.
- Modern Railways (1986) 'Studies in Success: Bathgate reopening' June.
- Mogridge M (1985) *Jam Yesterday, Jam Today and Jam Tomorrow?* University College London.
- Momenthy A (1991) 'Characteristics of Future Aviation Fuels' Transportation and Global Climate Change: Long-Run Options, Pacific Grove, California, 25-28 August.
- Muto S (1983) 'The aerodynamic drag coefficient of a passenger car and methods for reducing it' *International Journal of Vehicle Design*, op. cit.
- National Express (1989) Personal communication.

- Newman P and Kenworthy J (1990) *Cities and Automobile Dependence: An International Source Book* Gower.
- OECD (1982) *Automobile fuel consumption in actual traffic conditions*, OECD Road Research Group, Paris.
- OPCS (1984) *1981 Census* HMSO, London.
- OPCS (1990) *OPCS Monitor*, London.
- Owens S (1986) *Energy, Planning and Urban Form* Pion, London.
- Patten C (1989) Speech for Chatham House Conference, 5 December.
- Pearce D, Markyanda A and Barbier E (1989) *Blueprint for a Green Economy* Earthscan, London.
- Pearce T and Waters M (1980) *Cold start fuel consumption of a diesel and a petrol car*, Transport and Road Research Laboratory, Crowthorne.
- Pendyala R, Goulias K and Kitamura R (1991) *Impact of Telecommuting on Spatial and Temporal Patterns of Household Travel: An Assessment for the State of California Pilot Project Participants* Institute of Transportation Studies, University of California, Davis.
- Pinkerton L (1991) Personal communication, Isle of Man Government.
- Potter S (1976) *Transport and New Towns* The Open University.
- Potter S (1990) 'Rail electrification: environmental and political influences on future trends', presented to the conference *Evolution of Electric Traction 1890-1990*.
- Potter S (1991a) 'The Impact of Company-Financed Motoring on Public Transport' 1991 Public Transport Symposium, University of Newcastle upon Tyne, 9-11 April.
- Potter S (1991b) Personal communication.
- Potter S (1991c) *Company Cars: the case for major fiscal reform of company-assisted motoring* Briefing note to the Treasury, December.
- Potter S (1992a) 'Integrating Fiscal and Transport Policies' in Roberts J et al (eds) *Travel Sickness* Lawrence and Wishart.
- Potter S (1992b) 'Funding and Investment in an Integrated Transport Policy' in Roberts J et al (eds), op. cit.
- Potter S (1992c) Personal communication.

- Potter S and Hughes P (1990) *Vital Travel Statistics*, Transport 2000, London.
- Quimby A and Glendinning R (1991) *Perceived effectiveness and favourability towards some road accident countermeasures: a national survey* Transport and Road Research Laboratory, Crowthorne.
- Radford T (1992) 'Polar hole exposes climate's history' *The Guardian* 15 July.
- Ramanathan V (1988) 'The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment' *Science*, Vol 240 No 4850, pp.293-299.
- Redsell M, Lucas G and Ashford N (1988) *Comparison of on-road fuel consumption for diesel and petrol cars*, Transport and Road Research Laboratory, Crowthorne.
- Ross M (1990) Volkswagen test data, personal communication.
- Royal Town Planning Institute (1991) *Traffic Growth and Planning Policy* London.
- Schimel D (1990) 'Biogeochemical Feedbacks in the Earth System', in Leggett J, ed (1990) op. cit.
- Schipper L (1990) Personal communication.
- Schipper L (1991) 'Improved energy efficiency in the industrialised countries: past achievements, CO₂ emission prospects' *Energy Policy* Vol 19 No 2, pp.127-137.
- Schipper S, Duerr P, Steiner R, An F and Strøm S (1990) *Energy Use in Passenger Transport in OECD Countries: Changes between 1970 and 1987* Lawrence Berkeley Laboratory, University of California.
- Schneider S (1989) 'The Changing Global Climate', *Scientific American* Vol 261 No 3, pp.38-47.
- Schoon N (1991) 'A far cry from the milk float' *The Independent* 2 September.
- Society of Motor Manufacturers and Traders (1990) *The Motor Industry and the Greenhouse Effect*.
- South Coast Air Quality Management District (1989) *The Path to Clean Air: Attainment Strategies*.
- Sperling D and DeLuchi M (1989) 'Transportation Energy Futures' *Annual Review of Energy* 14, pp.375-424.

- Steadman P and Barrett M (1991) *The Potential Role of Town and Country Planning in Reducing Carbon Dioxide Emission* Centre for Configurational Studies, The Open University.
- Sturt A (1992) 'Going Dutch' *Town and Country Planning* Vol 61, No 2, pp.48-51, London.
- Timberlake L (1988) 'Global weather: what on Earth is happening?' *Telegraph Weekend*, 5 November.
- Transport and Road Research Laboratory (1987) *Demonstration Safety Car - ESV87*, Transport and Road Research Laboratory, Crowthorne.
- University of California, Los Angeles (1991) *Prospects for Alternative Fuel Vehicle Use and Production in Southern California* Lewis Center for Regional Policy Studies, Working Paper No 2.
- Von Hippel F and Levi B (1983) 'Automobile Fuel Efficiency: The Opportunity and the Weakness of Existing Market Incentives' *Resources and Conservation* 10, pp.103-124.
- Walsh M (1990) 'Motor Vehicles and Global Warming', in Leggett J, ed (1990) *Global Warming: The Greenpeace Report*, Oxford University Press.
- Walsh M (1991) 'Transportation Activity Trends and their Implications for Global Warming' presented at the conference *Transportation and Global Climate Change: Long-Run Options* Pacific Grove, California.
- Warr W (1991) 'The Ozone Layer: repairing the damage', in *U206 Environment*
- Warren A (1990) 'How Germany is rising to the carbon challenge' *The Guardian* 19 October.
- Watkins L (1991) *Air pollution from road vehicles* Transport and Road Research Laboratory, Crowthorne.
- Watson R (1989) *Car fuel consumption: its relationship to official list consumptions* Transport and Road Research Laboratory, Crowthorne.
- Watson R, Rodhe H, Oeschger H and Siegenthaler U (1990) 'Greenhouse Gases and Aerosols', in Houghton et al (1990) op. cit.
- Webb J (1991) 'Hydrogen-powered electric car sets sceptics wondering' *New Scientist* No 1775.

Weiss C (1990) 'Ethyl Alcohol as a Motor Fuel in Brazil' *Technology in Society* Vol 12, pp.255-282.

White (1986) *Comparison of Vehicle Costs* Paper C220/86, I. Mech. E., London.

Whitelegg J (1990a) 'European Instruments for an Environmental Transport Policy in the European Context' European Parliament hearing on 'Economic and Fiscal Incentives to Promote Environmental Policy Objectives', Brussels, 21-22 June.

Whitelegg J (1990b) 'The principle of environmental traffic management' in Tolley R, ed (1990) *The Greening of Urban Transport* Belhaven Press.

Whitelegg J (1991) 'ETR - a step beyond the fiscal quick fix' *Town & Country Planning* Vol 60, No 9, pp.270-273, London.

Withrington P (1990) Personal communication

Woodwell G (1990) 'The Effects of Global Warming', in Leggett J, ed (1990) op. cit.

Workhouse (1991) 'The lean burn engine' *Equinox* Channel Four Television.

Zeevenhooven N (1990), 'The energy consumption of various transport systems', in *Railways, Environment and Transport Quality*- a collection of expert papers prepared for the International Transport Workers' Federation.

Appendices

APPENDICES

Appendix 1

The calculation of CO₂ emissions from different forms of transport

Figure 2.2 in Chapter Two gives 1990 estimates of CO₂ emissions from different subsectors of transport, both passenger and freight. Below is a description of the method used to derive these figures.

For some modes, information is published on annual CO₂ emissions. For others, the method involves the conversion of annual fuel consumption data into annual quantities of CO₂, using information concerning the carbon content of different fuels. In both cases the source of data is the Department of Transport (1991).

The carbon content of petrol and diesel is 85.5 and 85.7 per cent by weight respectively (Bottomley, 1989). It is assumed that when the fuel is burned, all of the carbon is oxidised to form carbon dioxide. Thus the mass increases by a factor of 11/3, the ratio of the molar masses of carbon dioxide and elemental carbon.

Cars

In 1990, cars in Britain consumed 21.9 Mt of petrol and 1.0 Mt of diesel. Using the above figures for carbon contents, this represents 19.5 Mt of carbon, and 71.6 Mt of CO₂.

Buses and coaches

In 1990, buses and coaches consumed 1.1 Mt of diesel. Using the same method as for cars, this represents 3.3 Mt of CO₂.

APPENDICES

Appendix 1

The calculation of CO₂ emissions from different forms of transport

Figure 2.2 in Chapter Two gives 1990 estimates of CO₂ emissions from different subsectors of transport, both passenger and freight. Below is a description of the method used to derive these figures.

For some modes, information is published on annual CO₂ emissions. For others, the method involves the conversion of annual fuel consumption data into annual quantities of CO₂, using information concerning the carbon content of different fuels. In both cases the source of data is the Department of Transport (1991).

The carbon content of petrol and diesel is 85.5 and 85.7 per cent by weight respectively (Bottomley, 1989). It is assumed that when the fuel is burned, all of the carbon is oxidised to form carbon dioxide. Thus the mass increases by a factor of 11/3, the ratio of the molar masses of carbon dioxide and elemental carbon.

Cars

In 1990, cars in Britain consumed 21.9 Mt of petrol and 1.0 Mt of diesel. Using the above figures for carbon contents, this represents 19.5 Mt of carbon, and 71.6 Mt of CO₂.

Buses and coaches

In 1990, buses and coaches consumed 1.1 Mt of diesel. Using the same method as for cars, this represents 3.3 Mt of CO₂.

Goods vehicles

In 1990, goods vehicles consumed 2.2 Mt of petrol and 8.6 Mt of diesel. Using the same method as above, this represents 9.3 Mt of carbon, and 34.0 Mt of CO₂.

Air

In 1986, domestic air services in the UK consumed 12 PJ of energy (Department of Energy, 1989). Aviation fuel has an energy content of 46.4 GJ per tonne (Department of Energy, 1990), so this corresponds to an average consumption of 0.26 Mt. The carbon content of aviation fuel is assumed to be the same as that of petrol, 0.855 by weight. Thus domestic flights in 1986 consumed 0.22 Mt of carbon, and therefore produced 0.81 Mt of CO₂.

To update this figure to 1990, some growth must be included. A rounded-up figure of 0.9 Mt has been adopted.

Rail

In 1990, railways in Britain consumed 0.60 Mt of diesel and approximately 11.4 PJ of electricity (the 1989 figure for electricity is used, as the 1990 figure is not in usable form) (Department of Transport, 1991). The diesel component, using the above method, represents 1.9 Mt of CO₂. The electricity component is equal to 1.2 per cent of all electricity demand, and therefore 1.2 per cent of all CO₂ emissions from power stations. Figure 2.1 shows that power stations in 1989 were responsible for 191 Mt of CO₂ emissions (latest figure available), and so electric trains can be said to have produced an annual quantity of 2.3 Mt.

Adding the diesel and electric components gives a total annual CO₂ figure of 4.2 Mt.

Other

It is estimated that motorcycles account for marginally less than one per cent of petrol consumption in Britain, or approximately 0.24 million tonnes. This corresponds to a CO₂ production of 0.75 million tonnes. According to the Department of Transport (*op. cit.*), shipping, of which most is coastal, accounts for approximately 6 million tonnes.

Allowing for other forms of transport besides these, it is assumed that 'other' forms of transport produce 7.0 million tonnes of CO₂ per annum.

Total emissions of CO₂

The total figure for transport-based CO₂ emissions in 1990 is 121 Mt, obtained by adding the contributions of individual modes.

Appendix 2

The calculation of energy consumption by different travel modes

Figure 2.7 in Chapter Two shows the primary energy consumption of various travel modes. The data on which this figure is based are drawn from a variety of sources. Below are details of both the original data and the method used to convert them to megajoules per passenger kilometre.

Rail

The following figures were obtained from British Rail (1989):

A diesel-powered High Speed Train (HST) consumes approximately 4.4 litres per kilometre on average. Number of seats = 490.

An electric Class 91 (InterCity 225) consumes 18 kWh per kilometre. Number of seats = 564.

An electric Class 90 (175 km/h maximum) consumes approximately 16 kWh per km. Number of seats = 564.

A Class 321 Electric Multiple Unit (EMU) consumes 7.5 kWh per mile, with an average station spacing of 6 km. Number of seats = approximately 300.

A Class 156 two-car unit consumes on average 1.7 litres per km. Number of seats = 146.

The Department of Energy (1989) estimates the load factors of various types of surface train journey to be as follows:

High Speed Train:	0.39
Electric InterCity:	0.40
Electric Multiple Unit	0.22
Diesel Multiple Unit	0.22

Underground railway

The Department of Energy (1989) has derived the energy consumption and load factor of the London Underground, the only example of an urban underground railway in Britain. It estimates that London Underground trains consume 12.2 GJ per 100 train km, and that with

an average load factor of 0.15 the energy consumption is 0.22 MJ per place-km. 'Place' refers not only to seats but also to standing areas.

Light Rail Transit (LRT)

Carey (1991) gives details of the energy consumption of the Metrolink vehicles that have been supplied for Manchester's LRT scheme. Data are given for vehicles both with and without regenerative braking:

With regenerative braking:	2.4859 kWh per km (on-street); 2.4299 kWh per km (off-street).
Without regenerative braking:	3.4426 kWh per km (on-street); 3.5482 kWh per km (off-street).

There is some question as to whether regenerative braking is of use when there are no LRT vehicles in the vicinity that can use the regenerated electricity. It is thus assumed that the true energy consumption lies midway between the 'with' and 'without' values. Similarly it is assumed that there is a two-way split between on and off-street running. The data given in Figure 2.7 assume an energy consumption of 2.98 kWh per km.

Details of passenger capacity are given as 265 persons fully laden, and 82 seats. It is assumed that LRT vehicles will operate with similar load factors to those of buses, namely 0.5.

Bus

The following figures were obtained from an East Midlands bus operator and from London Buses (1989):

A double-decker bus returns an average of 7 mpg. Number of seats = 74.

A single-decker bus returns an average of 8 mpg. Number of seats = 49.

A minibus returns an average of 16 mpg. Number of seats = 20.

The Department of Energy (1989) has estimated the average load factors of different bus services to be as follows:

Urban double-decker bus:	0.50 - 0.75
Suburban double-decker bus:	0.25 - 0.50

Suburban single-decker coach:	0.25 - 0.50
Suburban minibus:	0.25 - 0.50

In Figure 2.7, no distinction is made between urban and suburban services. An average load factor of 0.50 is assumed for all types of bus.

Express coach

According to National Express (1989) the average fuel consumption of express coaches is 'just over 10 mpg'. The number of seats on a vehicle is around 46, of which typically two-thirds are occupied.

Car

Watson (1989) has established a formula for converting the new-car fuel consumption data issued by the Government into a 'real-life' figure. Using the official fuel consumption data, average figures are derived (see below) for each category of car. The formula applies only to petrol-engined cars, so in the case of diesel cars the test data published by What Car? (1991) have been used.

For all four categories, Ford cars have been used. This is because Ford is the most common brand of car in Britain, and because the author considers the Ford range to be sufficiently wide to cover all categories of vehicle.

Large petrol car (Ford Granada 2.9):	21.8 mpg or 13.0 l/100km
Small petrol car (Ford Fiesta 1.1):	44.6 mpg or 6.3 l/100km
Large diesel car (Ford Granada 2.5D):	35.6 mpg or 7.9 l/100km
Small diesel car (Ford Fiesta 1.8D):	54.6 mpg or 5.2 l/100km

The occupancy of cars can be derived by comparing figures for annual car miles with those for annual passenger miles by car (Department of Transport, 1990). For several years the average number of people carried by a car has been constant at 1.75.

Motorcycles

Motorcycle Weekly (undated) have published fuel economy data for different engine size categories. By combining these figures with the distribution of engine sizes in use (Department of Transport, 1990) it is possible to obtain an average figure for motorcycle fuel consumption. The results are as follows:

Motorcycles (over 50cc):	60.0 mpg or 4.7 l/100km
Mopeds (under 50cc):	75.9 mpg or 3.7 l/100km

Hillman and Whalley (1983) estimate the average occupancy of motorcycles to be 1.1, and that of mopeds to be 1.0. The use of mopeds with two riders is considered uncommon.

Air

The Department of Energy (1989) has considered all types of air travel in the UK, and covered a variety of different aircraft. It estimates that domestic flights in 1986 averaged 170 MJ per aircraft km, and 3.5 MJ per passenger km (an average occupancy of 49 persons). It notes that this type of service is associated with a load factor of around 0.65.

Bicycle and walking

Watkins and Wilson (1985) have calculated the energy consumption of walking and cycling. For walking, they estimate 3.2 kJ per km per kg mass of the person. For cycling they estimate 0.63 kJ per km for each kg of bicycle and rider combined.

Assuming the mass of a person to be 70 kg, and that of a bicycle to be 20 kg, this represents 0.22 MJ per mile for walking and 0.057 MJ per mile for cycling.

Conversion to primary energy

The data presented in Figure 1 are in terms of primary energy, and have been converted from the 'operating' energy consumption data through a number of assumptions. Zeevenhooven (1990) has estimated the efficiency with which fossil fuels are produced and transmitted to the point of use to be as follows:

Petrol for cars	0.89
Diesel for cars	0.97
Fuel for aircraft	0.96

For convenience it is assumed that the 'diesel for cars' figure may be used for diesel-driven rail locomotives. The efficiency with which diesel is supplied to railway stock is unlikely to be lower than the corresponding figure for cars, in the view of the author, since car refuelling involves a greater number of outlets, and smaller volumes of fuel for each refill.

(Although rail diesel is of a slightly lower grade than DERV, the difference in carbon content is unlikely to be significant.)

Davies (1991) estimates that power stations generating electricity for the railways operate at a typical efficiency of 30 per cent. Transmission to point of use, plus reduction to operating voltage, is estimated to lower this efficiency to 23 per cent. In the absence of more detailed information, the latter figure is assumed to be correct for all forms of electric rail traction.

Combining the energy consumption data with the conversion factors above, it is possible to derive primary energy requirement data for each mode. This information is summarised in the table below. Additionally, the conversion to GJ is made through the relationships

$$1 \text{ kWh} = 3.6 \text{ MJ} = 0.0036 \text{ GJ}$$

$$\text{Diesel energy content} = 0.0461 \text{ GJ per kg; 1 litre weighs 0.847 kg}$$

$$\text{Petrol energy content} = 0.0470 \text{ GJ per kg; 1 litre weighs 0.738 kg}$$

(Department of Energy, 1990)

The figures in brackets (where applicable) are the equivalent data from the Department of Energy (1989), for comparison. Generally the agreement is good, with the discrepancy due mainly to varying definitions within each category.

Mode	Primary energy consumption		Number of persons carried:	
	(GJ per 100 km)		Maximum	Average
Rail:				
InterCity diesel	17.5	(19.7)	490	191
InterCity electric	28.2	(23.9)	564	226
Suburban electric	11.7	(8.8)	300	66
Suburban diesel	6.84	(10.0)	146	32
Underground	12.2		555	83
Bus:				
Double decker	1.62	(1.69)	74	37
Single decker	1.42	(0.99)	49	25
Minibus	0.71	(0.60)	20	10
Express coach	1.11	(1.25)	46	30
Car:				
Large petrol	0.51		5	1.75
Small petrol	0.25		5	1.75
Large diesel	0.32		5	1.75
Small diesel	0.21		5	1.75
Motorcycle	0.18		2	1.1
Moped	0.14		1	1.0
LRT	4.66	(2.4 - 4.8)	265	133
Air	17.7		75	49
Walk	0.014		(1)	(1)
Cycle	0.003		1	1

Appendix 3

Reduction in CO₂ emissions resulting from the full enforcement of 70 mph speed limits

The national speed limit in the UK is 70 mph. Observance of this limit is generally poor. Vehicle speeds at free-flow locations on motorways around Britain were monitored between January and June 1991 by the Department of Transport,¹ and the average speed of cars was found to be 75 mph, with 72 per cent of cars exceeding the speed limit. One third of cars were travelling above 80 mph, whilst one car in 25 was exceeding 90 mph. The results are summarised below.

Measured vehicle speeds on motorways

Speed range	Number of vehicles (%)		
	Cars	Motorcycles	Coaches
0 - 50 mph	1	12	3
50 - 60 mph	7	7	17
60 - 65 mph	7	7	17
65 - 70 mph	13	10	41
70 - 75 mph	23	18	21
75 - 80 mph	15	10	1
80 - 90 mph	29	20	0
Over 90 mph	4	17	0
All speeds	100	100	100

Source: Department of Transport, 1991b.

It should be noted that these speeds do not necessarily represent average motorway driving, as they were not measured at congested sites. The authors indicate that 'the results cannot be

¹ Local Transport Today (1991) 'Over two thirds of cars break motorway speed limit' No 68, p.4.

used for complete journey time estimation or overall average speed estimates' (Department of Transport, 1991b).

The results indicate that if the speed limit were successfully enforced, 72 per cent of traffic would be affected. The remaining 28 per cent are already travelling below the maximum speed.

To evaluate the effect of 'full enforcement' on fuel economy, it is necessary to determine the average speed of those cars that are exceeding the limit.

Most of the 'speeding' cars are travelling below 80 mph, while the average speed for *all* cars is 75 mph. This indicates that the average 'speeding' car is travelling between 75 and 80 mph. It is assumed here that the value is 77 mph.

This figure must be reduced to account for the fact that slower stretches of motorway, and congested sections, were not included in the survey. It is therefore assumed that the average 'speeding' car has a speed of 75 mph.

Therefore the full enforcement of a 70 mph speed limit on motorways would affect 72 per cent of cars, with an average reduction in speed from 75 to 70 mph. A close inspection of Figure 3.4 (Chapter Three) indicates that such a change would result in a reduction in fuel consumption from 10.2 to 9.3 l/100km for the 1600cc Vauxhall Cavalier, a fuel saving of nine per cent per kilometre travelled.

The Department of Transport (1991) gives a figure of 46.65 billion car kilometres on motorways in 1990. If the average fuel saving in speed-reduced cars is the same as that of the Cavalier 1600 (considered near-average), the 70 mph speed limit implies an annual saving of 450 million litres, or 330,000 tonnes, of fuel.

The actual reduction in car fuel consumption overall would be greater than this value, since motorways are not the only roads in the UK with a 70 mph speed limit. An increasing number of major roads are dual carriageways with a 70 mph limit.

The author estimates that if these additional factors are included in the calculation, the amount of fuel saved would increase by 50 per cent to approximately 500,000 tonnes per annum. This implies a two per cent improvement in average car fuel consumption, which would take place in the period up to full enforcement.

Appendix 4

The use of Census data to estimate the influence of urban travel measures

The 1981 Census (OPCS, 1984) gives details of the journeys made by people from home to work. This information may be used to estimate the number of journeys that might be affected by urban traffic measures such as area licensing.

In England and Wales, 20.81 million people were in employment in 1981. Of all the jobs, approximately 7.5 per cent were in large urban areas, as the following list illustrates:

London (West End and City)	1,070,170
Manchester & Salford city centres	106,950
Liverpool city centre	92,690
Sheffield city centre	59,270
Newcastle upon Tyne city centre	57,620
Birmingham city centre	101,190
Leeds city centre	59,010
All of the above	1,546,900, or 7.4% of all jobs in England and Wales

Potter (1992c) has surveyed Census data from different types of area in order to examine the type of journeys typically undertaken by rural, intermediate and urban commuters. In London boroughs, typically 10 to 20 per cent of the working population travels to the City and Westminster. This figure rises to between 15 and 35 per cent if other parts of Central London are included. An average of 20 per cent is assumed.

In other urban areas, a similar figure is indicated by the Census results.

Appendix 5

Articles and papers published by the author during the course of this study

'The role of passenger transport in CO₂ reduction strategies' *Energy Policy* Vol 19 No 2, pp.149-160, 1991.

'Options for reducing CO₂ emissions from personal travel in Europe' *International Journal of Vehicle Design* Vol 13, No 2, pp.114-124, 1992.

'Drive-Through Solutions to Global Warming' *Energy Policy* Vol 20 No 4, pp.376-378, 1992.

'How Green is my Maestro?' *Town & Country Planning* Vol 59 No 1, pp.22-25, 1990.

'Exhausting the Atmosphere' *Town & Country Planning* Vol 60, No 9, pp.267-269, 1991.

'Milestone in a rapidly moving policy sector' *Town & Country Planning* Vol 61 No 6, p.186, 1992.

'Californian air: Roger Rabbit hits back' *New Democrat International* November/December 1990.

'Gas is greener on diesel ride' *The Guardian* 12 August 1989.

Co-authored reports and articles:

Vital Travel Statistics 1990 Transport 2000, 1990.

The Greenhouse Effect and Energy Policy, evidence submitted to the House of Commons Energy Committee inquiry, February 1989.

'Parkinson's disease' *New Civil Engineer* 24 May 1990.

'On the road to environmental disaster' *Daily Telegraph* 24 July 1989.