Strategies to Reduce Greenhouse Gas Emissions from Road Transport: Analytical Methods

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

The Mission of the OECD Programme of Research on Road Transport and Intermodal Linkages (RTR) Programme is to promote economic development in its Member countries by enhancing transport safety, efficiency and sustainability through a co-operative research programme on road and intermodal transport. To achieve this objective, the Programme recommends options for the development and implementation of effective transport policies for Members, and encourages outreach activities for non-member countries. All 30 OECD Member countries participate in the Programme.

The 1998-2000 Programme of Work included a Working Group on "Analytical Methods of Road Transport Sector Strategies to Reduce Greenhouse Gas Emissions". The Working Group was chaired by Mr. Jean Delsey (INRETS, France) and the following countries participated in the study: Australia, Canada, Czech Republic, Denmark, France, Hungary, Italy, Japan, Korea, the Netherlands, New Zealand, Norway, Switzerland, the United Kingdom and the United States.

The Working Group investigated recent trends in CO_2 emissions from road transport, and reviewed models that have been developed by OECD Member countries to forecast greenhouse gas emissions from road transport. In addition, the Working Group analysed models that have been used to assess policy options to reduce CO_2 emissions and provide insight on future developments.

ABSTRACT
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Approximately 27% of total OECD CO_2 emissions come from transport. Within this, road-based transport accounts for approximately 80%. The OECD Road Transport and Intermodal Linkages Research Programme established a Working Group to undertake a comprehensive study on CO_2 emissions from road transport, with the aim of providing a useful framework for assessing the strategies of the road transport sector in reducing emissions on a global scale.

The Kyoto Protocol seeks an average 5.2% reduction in economy-wide greenhouse gases emissions compared to 1990 levels in industrialised countries and countries in transition (Annex I parties to the UN Framework Convention on Climate Change) by 2008-12. Given recent developments in transport growth, it would be very challenging for the road transport sector in OECD countries to achieve substantial reductions in CO_2 emissions over the same period.

However, measures exist that can contribute to alleviate the road transport share of greenhouse gases. The most effective approach to reducing GHG emissions by private cars and road transport should involve a package or combination of measures, such as: voluntary agreement between vehicle manufacturers and government to produce low-fuel consumption vehicles; graduated vehicle taxes; fuel taxes and excise duties; consumer information; and promotion of greater fuel efficiency in the different sectors involved.

***Field classification*:** Environment highway and transport planning.

***Field number*:** 15, 21.

***Keywords*:** Air pollution, carbon dioxide, environment, evaluation, fuel, fuel consumption, gas, greenhouse gas emissions, tax, traffic, traffic control, traffic restraint, transport, vehicle.

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EXECUTIVE SUMMARY

Scientific research suggests that the earth's average temperature is rising slowly but steadily. Increased global emissions of greenhouse gases (carbon dioxide, methane, chlorofluorocarbons and nitrous oxide) have contributed to this phenomenon. The Intergovernmental Panel on Climate Change (IPCC) has predicted a rise in global temperatures of between 1 and 2° Celsius by 2020 and between 2 and 5° Celsius by 2070. Increased international awareness of this global temperature increase has led to considerable international effort, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, to prevent climate change by attempting to reduce CO_2 emissions.

Approximately 27% of total OECD CO_2 emissions come from transport. Within this, road-based transport accounts for approximately 80%. The OECD Road Transport and Intermodal Linkages Research Programme established a Working Group to undertake a comprehensive study on CO_2 emissions from road transport, with the aim of providing a useful framework for assessing the strategies of the road transport sector in reducing emissions.

Approach and aim of the report

The report attempts to address three key questions:

- First, what steps are being taken by road transport in the way of policies or measures to reduce or stabilise global road transport-related CO_2 emissions (for example, through national legislation, voluntary agreements or fiscal measures)? Most countries have adopted a combination of policies and measures to form a comprehensive strategy to reduce CO_2 emissions.
- Second, what evaluation frameworks exist to assess the impact of these policies and measures, both *ex ante* and *ex post*? Several countries have adopted different modelling approaches, described as "bottom up" or "top down", to reduce CO_2 emissions. This report aims to provide examples of these models, without making a comprehensive assessment of individual countries' modelling capacity.
- Finally, what are the future trends in global CO_2 emissions for the industry and transport sectors, particularly for the road transport? What role can evaluation models assume in facilitating the development and implementation of strategies to assist in the reduction of CO_2 emissions on a global scale?

CONCLUSIONS AND RECOMMENDATIONS

Recent growth in CO_2 emissions from road transport

- Scientific research on the impact of greenhouse gases – especially CO_2 and methane – is now producing convergent results: the evidence points towards a slow but steady rise in the earth's average temperature.
- Research undertaken in relation to overall emissions and those from the transport sector suggests that:
  - Total emissions of CO_2 are increasing in all OECD countries and are growing faster in newly industrialised countries.
  - Similarly, the road transport share of total CO_2 emissions is increasing, as is the absolute level of CO_2 emission tonnage from road transport.
  - Freight transport by road is increasing more rapidly than total freight transport. In several large OECD countries, the share of freight transport (tonnage) by road is 75% of total freight transport and this share is continuing to rise.
- The Kyoto Protocol seeks an average 5.2% reduction in economy-wide GHG emissions in industrialised countries and economies in transition (Annex I parties to the UN Framework Convention on Climate Change) by 2008-2012 against 1990 levels. Given recent developments in transport growth, it would be very challenging for the road transport sector in OECD countries to achieve substantial reductions in CO_2 emissions over the same period that could contribute proportionately to overall CO_2 reductions.

Policies and measures to reduce CO_2 emissions by road transport

- A number of OECD countries have taken measures to reduce CO_2 emissions by road transport; these focus on fuel intensity and fuel economy, such as fuel taxes and voluntary agreements with industry to improve vehicle fuel efficiency.
- Some measures take the form of national legislation to limit the average fuel consumption of new cars supplied to the market. Others are designed to limit passenger car traffic in urban areas in order to reduce air pollution and to improve the use of public transport, with an indirect but positive impact on CO_2 emissions.
- Measures such as transport demand management and traffic management systems are often supported by specific taxes, promotion of public transport systems to encourage voluntary transfer from cars, support for use of alternative fuels, etc. These measures face a different range of problems:
  - T*he problem of scale*: measures focused on the centres of metropolitan areas will only have a small impact on metropolitan-wide CO_2 emissions from road traffic.
  - P*olitical problems*: some of the proposed measures, such as raising prices through road tolls or taxes, are politically difficult to apply.
- The impact of alternative fuels continues to be rather small. Vehicles powered by alternative fuels are expensive and few countries have an extensive refuelling network; as a result, such vehicles are slow to penetrate the market. It is important to consider the overall impact on total

CO_2 emissions when analysing the potential contribution of alternative fuels (for example, with electric vehicles, taking into account the additional emissions associated with generation of the electricity used for motive power, whether produced from oil, coal or gas).

- The most effective policies and measures for reducing GHG emissions by private cars and road transport – and contributing to sustainable development – seem likely to involve a package or combination of measures, such as: voluntary agreements between vehicle manufacturers and government to produce low-fuel consumption vehicles; graduated vehicle taxes; fuel taxes and excise duties; consumer information; and promotion of greater fuel efficiency in the different sectors involved (*e.g.* within the road haulage and bus industries).
- It is also important to educate local policy makers about the relevance of measures undertaken at a local level in the reduction of GHG emissions, even if the largest GHG reductions can be achieved by measures taken at national and international levels.

Assessment and modelling methods

- A large number of forecasting models have been developed to evaluate the potential impact of different measures and new technologies, in particular focussing on: overall road traffic; passenger car and truck traffic demand; the transfer of demand between different modes; and fuel consumption, including the impact of fuel taxes on the demand for fuel. The number of models available reflects the efforts made by all OECD countries in this sector.
- Different modelling, assessment and evaluation techniques have been developed – for example, using a "bottom-up" or a "top-down" approach. Most of these seek a similar outcome; namely, cost-efficiency per tonne of CO_2 reduced.
- The task of forecasting CO_2 emissions is ambitious and existing models have many limitations and constraints:
  - Available data are often not sufficiently detailed (in terms of key variables such as hourly traffic, freight vehicle shares, fuel consumption per vehicle, average annual distance travelled).
  - Links between parameters (such as econometric parameters) are not always explained or validated, and models sometimes use too many equations (some models consist of more than 100 econometric equations) and assumptions.
  - Hypotheses are sometimes too rigid and methodology may not be sufficiently flexible (*e.g.* to deal with variations in economic growth or changes in the growth and composition of the vehicle fleet).
- Most models have a number of shortcomings that need to be recognised and addressed:
  - Simplifications are necessary, which lead to some modelling errors.
  - A single general model is not possible; different models are needed for each application.
  - The accuracy of the model results is unknown.
  - Although highly desirable, comparability between models across different countries is difficult to achieve and the extent of comparability is uncertain and difficult to assess (due to different hypotheses, equations and data).
  - While existing models have been useful for forecasting, there is very little experience at the national level with evaluation of changes once a measure has been applied. E*x post* evaluation can be very useful in validating the impact of technical, tax or local policy measures. Therefore, it may be valuable to seek sufficient funds from the budget for a project to conduct an *ex post* evaluation. However, *ex post* evaluation often constitutes a very complex task that is difficult to undertake, particularly since it is often only possible only a long time after the measure is applied. Further *ex post* evaluation is often complicated through the intervention of other measures which make it difficult to attribute outcomes to the primary measures under review.

Future trends

- Car ownership per 1 000 inhabitants is expected to continue to rise everywhere, and most countries are experiencing substantial increases in the driving licence rate. The average annual distance travelled per passenger car is also increasing leading to a substantial increase in total mileage driven each year.
- Continued strong growth is expected for freight transport. Road transport is expected to capture an increasing share of the growing freight transport markets. Even in industrialised OECD countries, which have modern railway networks, road transport is capturing almost all the increases in freight transport generated by economic growth.
- Some technological advances are anticipated that will greatly reduce fuel consumption per vehicle:
  - In the short term (by 2010), further modifications are planned for motor vehicle engines to reduce fuel consumption and GHG emissions. These will involve continued use of diesel or gasoline engines, but the engines will be downsized, with camless systems and direct fuel injection. Hybrid vehicles are already being marketed with a combination of smaller, more fuel-efficient traditional engines and alternative power sources.
  - In the long term (after 2010), more advanced and fuel-efficient solutions could appear, such as fuel cell generators with hydrogen or methanol as their primary fuel.
  - In all cases involving alternative fuels, it is important to assess the impact on GHG emissions, taking into account the emissions generated in the production of the fuels being used.
- Voluntary agreements between manufacturers and governments could accelerate the technological evolution towards low-fuel vehicles.
- However, given the time required for new vehicles to penetrate the market and for vehicles in the existing fleet to turn over, significant emission reductions attributable to fleet turnover could not be expected for at least 10 to 20 years.
- CO_2 reduction assessments need to be based on the real use of vehicles. Fuel consumption and CO_2 emission results obtained from field-tests during "official test" cycles are different from those of real world driving – when occupants use accessories such as lights, air conditioning and other electric equipment which are relatively fuel intensive. Consideration also needs to be given to the temporal pattern of use of the vehicles concerned – daytime, night-time, summer and winter.
- When viewed together, the outlook for unit fuel consumption, average annual distance travelled and the number of vehicles in use indicates that global CO_2 emissions from passenger cars will not decrease by 2010-15, but rather will strongly increase.
- Given the projections for passenger car and road transport growth and the extent of anticipated fuel intensity/fuel efficiency improvements, use of transport fuel will continue to grow in OECD (and non-OECD) countries. Unless additional corrective action is taken, GHG emissions from road transport will continue to increase under a business-as-usual scenario. However, the use of economic measures such as fuel taxes, vehicle taxes based on vehicle fuel efficiency and road pricing may moderate this expected growth by reducing demand overall and encouraging the shift to more fuel efficient/low emission vehicles.

RECOMMENDATIONS

- Transport models used to forecast GHG emissions and to evaluate the cost-effectiveness of measures to reduce greenhouse gas emissions need to be developed/refined further and their limitations better understood. The underlying data, assumptions, hypotheses and links between parameters, shortcomings and accuracy of the results all require attention. Model limitations can affect cost-benefit assessments of CO_2 and GHG reductions expected to result from policy measures and technological advances.

- A major element of policy packages directed towards improved fuel efficiency should be an emphasis on very low-fuel consumption vehicles coupled with fuel taxes and road pricing.
- Extensive research must be undertaken to examine effective ways to accelerate the adoption of low emission vehicles, looking primarily at the constraints, such as infrastructure requirements and safety.
- Assessments of fuel efficiency and GHG emissions need to be based on the real use of vehicles rather than on "official cycle" estimates.
- Alternative fuels, hybrid vehicles, fuel cell generators and other new technologies offer prospects for reducing CO_2 emissions, but evaluations need to encompass the overall CO_2 and GHG changes, taking into account those released during fuel production.
- Given the expected trends in CO_2 and GHG emissions under business as usual scenarios, further research is required on the development and application of models to evaluate policy options and measures that could contain increases and lead to reductions in the longer term. For urban areas, assessments need to include the impact of measures applied in existing cities to optimise travel demand and contain greenhouse gas emissions from passenger vehicles and freight transport. There is also a need to explore the contributions that could be made by urban planning – taking into account transport requirements in OECD countries – in optimising travel demand and containing emissions from road vehicles.
- Research on road transport-related global warming should be conducted on a recurrent basis at intervals of several years since the issue of global warming includes many uncertainties as well as disparities in forecasts on the impact of policies, technologies, transport demand, etc. on CO_2 emissions.
- It is highly desirable for forecasting models to be validated using *ex post* evaluations. Sufficient funds for such evaluations should be sought at the outset, recognising that *ex post* evaluations are often difficult and costly to undertake.
- There is a need to forge closer links between forecasting models, evaluation frameworks and he development of policies to reduce CO_2 emissions, including the monitoring and review of policy effectiveness.

Chapter 1

INTRODUCTION

Context

Climate change is potentially one of the most serious environmental threats facing the world today. Over the last few years, extreme weather conditions have shown how vulnerable society is to changes in the earth's climate, and how disastrous the impacts can be.

While it is difficult to determine whether individual events are the direct result of man-made changes to the climate, at the global level, temperatures rose by approximately 0.6° centigrade during the last century. The 1990s included seven of the ten warmest years on record and 1998 was the warmest year during a 140-year period. Scientists warn that we are about to enter a global warming phase during which the Earth's temperature is expected to rise significantly. The Intergovernmental Panel on Climate Change (IPCC) has forecast that global temperatures will rise between 1° and 2° by 2020, and between 2° and 5° by 2070.

Scientific evidence is mounting to show that man-made greenhouse gas emissions have a noticeable effect on the Earth's climate through the "Greenhouse Effect".

Figure 1 illustrates the mechanism of greenhouse gases.

Awareness of the global scale of emissions of greenhouse gases (carbon dioxide CO_2, methane CH_4, chlorofluorocarbons CFC and nitrous oxide N_2O) has increased over recent years. Scientists have noted that the average carbon dioxide content of the Earth's atmosphere is steadily increasing. Some climate change is now inevitable – the greenhouse gases that have already accumulated in the atmosphere make it impossible to avoid some rise in temperature. However, the worst effects of climate change can be avoided if the international community acts now to reduce emissions and, in time, to stabilise the levels of carbon dioxide in the atmosphere. International efforts such as the United Nations Framework Convention on Climate Change and the Kyoto Protocol target that goal.

Greenhouse gas emissions from transport

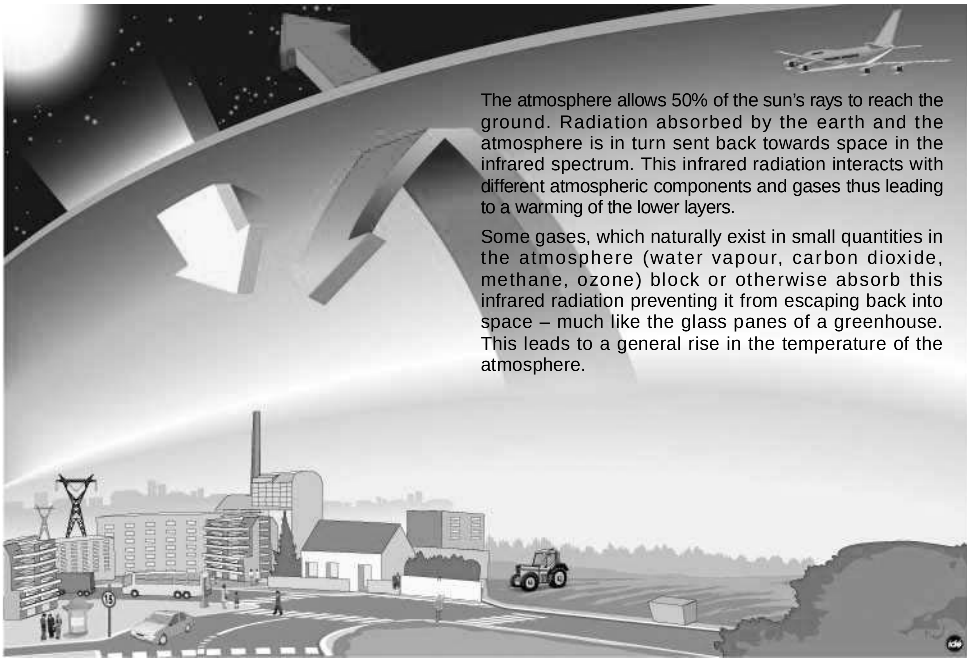
Naturally occurring greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Emissions from transport, and especially motor vehicles, add considerably to the levels of greenhouse gases in the atmosphere. Transport accounts for approximately 27% of total CO_2 emissions in OECD countries. Road transport generally accounts for approximately 55-99% of greenhouse gases from transport. Of this, two-thirds are attributable to the private car – primarily in the form of CO_2.

This report focuses on the contributions of road-based transport by looking at the some of the actions being taken by countries to contain and reduce emissions increases, including an assessment of how the effects of such policies and measures are modelled.

Timeframe

The main part of the report focuses on the period 2000-10. The section on future trends focuses on the period after 2010. This timeframe is appropriate since no major revolution in car technology can be applied on a large scale in terms of fleet composition before 2010. Car manufacturers have already

Figure 1. **The mechanisms of greenhouse gases**



Source: French Interministerial task force for climate change.

begun to commercialise the first of the low-fuel consumption vehicles that will produce fewer emissions over the next decade.

Current low-fuel consumption models incorporate the technology necessary to achieve substantial reductions in fuel consumption and emissions (for example, direct fuel injection for both diesel and gasoline engines). As a result, European car manufacturers should be able to satisfy their commitments under the Voluntary Agreement for emissions reduction concluded between ACEA (on behalf of the motor vehicle manufacturers) and the European Commission. Voluntary agreements also apply to Japanese and Korean car manufacturers and are based on the average CO_2 emissions of new passenger cars. However, while some technologies may help to contribute to the achievement of the objectives in a technical sense, the cost-effectiveness of their implementation from a manufacturer's perspective may raise other problems. For example, the ability to meet the agreements without sulphur-free fuel is a key challenge. The Voluntary Agreement specifies an emissions reduction target of 140 g CO_2/km before 2008 across their global vehicle production (see Chapter 3 for further details).

A further reason to support the year 2010 horizon is that it would be very challenging to drastically modify people's preference for the use of cars prior to this date, particularly in and around cities and other urban areas. Travel patterns depend on the existing spatial layout of urban and suburban development (*e.g.* the relative location of homes, jobs, commercial centres, etc.). Also, transport administrations have established plans and, in many cases, expenditure programmes covering current and future development of urban and rural highway networks for much of the next ten-year period, to meet those needs.

Any major modifications in technology or the use of cars could be expected to occur at a later stage, the earliest being from 2010-15. Over this time period, there is likely to be a larger impact on global CO_2 emissions through the replacement of high-fuel consumption vehicles (with the general availability of low-fuel consumption vehicles unlikely to take effect before then).

For the last 60 years, there has been a direct link between economic growth and transport emissions. The period 2010-15 is critical if OECD countries are to meet the challenge to reduce CO_2 emissions without constraining economic growth.

The report provides an overview of various policies implemented by different countries and some of the results that could contribute to achieving these objectives. Several OECD countries prepared and applied different measures to reduce fuel consumption by road transport before the Kyoto Conference (in some cases in the early 1990s). The results of these measures are evaluated where possible.

Working method and objectives

The work was undertaken by a working group comprising members from eleven countries, supported by the OECD Secretariat. The working group's method consisted of plenary sessions and analysis of written material, data, methodologies and results from different countries.

The objectives were as follows:

- Analyse recent trends of CO_2 emissions from road transport.
- Assess measures aimed at reducing CO_2 emissions from road transport.
- Evaluate methodologies used to assess the impact of the measures, and their applications and results in OECD countries.
- Forecast preliminary future trends on GHG emissions.
- Provide policy conclusions to transport policy makers and transport analysts alike.

Structure and content of the report

The structure of the report is as follows:

- Chapter 2 analyses the recent growth in CO_2, emissions from road transport for passenger cars and for freight in OECD and non-OECD countries, including the respective growth and contribution of diesel and gasoline uses.
- Chapter 3 reviews different policies and measures to reduce CO_2 emissions from road transport. Targets are indicated where known. Some measures are specific to a particular country, while others apply to a region (such as the agreement between the ACEA and the European Commission).
- Chapter 4 provides an overview of modelling methods used in different countries to assess possible measures to reduce CO_2 emissions. Analysis of the limitations and uncertainties of many of these models is an important part of this chapter. Discussion covers shortcomings in the application of the available models, such as data quality and lack of *ex post* evaluation.
- Chapter 5 examines future trends in terms of transport volume and its likely impact on GHG emissions as well as future technological developments that will enable reductions in GHG emissions increases.

Chapter 2

RECENT TRENDS IN CO_2 EMISSIONS FROM ROAD TRANSPORT*

Introduction

The transport sector comprises road vehicles, trains, ships and aircraft. Road transport accounts for between 55% and 99% of greenhouse gases from transport, of which two-thirds are attributable to the private car, primarily in the form of CO_2. The demand for road transport has dominated the demand for energy in the transport sector and is likely to continue to do so. Trends have shown substantial growth in greenhouse gases attributable to the transport sector in the majority of Annex I Countries (see Appendix A). To date, surprisingly little progress has been made in reducing emissions from the transport sector, and projections point to continued growth.

This chapter presents trends in CO_2 emissions from road transport for the period 1990-99 for the majority of OECD countries and some other countries, based upon IEA data. The data are presented in various country groupings as well as for individual countries. The chapter also provides a brief description of the methods used by countries to obtain the emission data requested as part of international obligations.

Local and global pollutants from road transport

Naturally occurring greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Emissions from motor vehicles add considerably to the levels of greenhouse gases in the atmosphere.

Carbon dioxide

CO_2 and water vapour are the major exhaust components emitted by engines, after combustion of petroleum-based fuels (gasoline, diesel fuel, natural gas, etc.). CO_2 represents more than 99% by mass of all the gaseous components of exhaust (CO_2, CO, HC, NO_x, etc.). With catalytic and other exhaust systems, a large part of the carbon monoxide (CO) and hydrocarbons (HC) is oxidised to CO_2 and H_2O. This explains why CO_2 is considered the predominant form of pollution emitted from internal combustion engines.

Methane

Some buses, trucks (both light-duty and heavy-duty) and passenger cars use compressed natural gas for fuel. Natural gas from fossil-bearing deposits is largely comprised of methane (82-95%), it also resultsfrom plant fermentation. It can be stocked in gaseous or liquid forms. Usage is likely to increase in the future for various reasons, the main one being that the use of compressed natural gas (CNG) by motor vehicles could contribute to a reduction in CO_2 emissions from such vehicles by 10-25% compared to vehicles powered with gasoline engines. CNG also produces less CO, HC, and NO_x – a particularly important consideration in urban areas. However, even with catalytic exhaust systems, methane (CH_4) emissions in exhaust gases remain significant. A distinguishing characteristic of methane

* The data on GHG emissions presented in this chapter are given in equivalent CO_2. Data may also be given in equivalent carbon. The relationship between the two is: 1 Mt CO_2 = 0.2727 Mt C.

is that 1 gram of CH_4 has a greenhouse effect which is nearly 21 times greater than that of 1 gram of CO_2. It is therefore important to take methane emissions into account in this study.

Noxious emissions

There are a number of concerns with vehicle emissions in addition to their global warming/ greenhouse effect. In areas of high concentration, particularly in cities, motor vehicle emissions pose direct risks to human health. This report focuses on methods to reduce greenhouse gas emissions; however, consideration also needs to be given to the importance of not increasing – and if possible reducing – the levels of noxious motor vehicle emissions at the same time as reducing greenhouse gas emissions.

Nitrogen oxides

N*itrogen oxide* emissions from vehicles produce a variety of adverse health and environmental effects. Once in the atmosphere, NO_x emissions react chemically with other pollutants to form tropospheric ozone (the primary component of photochemical smog) and other toxic pollutants. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infection (such as influenza). NO_x emissions are an important precursor to acid rain that may affect both terrestrial and aquatic ecosystems. Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility.

The most important contributors to worldwide emissions of NO_x are heavy-duty vehicles and buses, responsible for half the world's emissions of motor vehicle-related NO_x in spite of a comparatively small share (around 5%) of the world vehicle population.

Diesel particulates

P*articulate matter* is the general term for the mixture of solid particles and liquid droplets found in the air. Particulate matter includes dust, dirt, soot, smoke and liquid droplets. It can be emitted into the air from natural or man-made sources, such as windblown dust, motor vehicles, construction sites, factories and fires. Particles are also formed in the atmosphere by condensation or through the transformation of emitted gases such as sulphur dioxide, nitrogen oxides, and volatile organic compounds.

Scientific studies show a link between particulate matter (alone or in combination with other air pollutants) and a series of health effects. Motor vehicle particle emissions and the particles formed by the transformation of motor vehicle gaseous emissions tend to be in the fine particle range. Fine particles (those less than 2.5 micrometers in diameter) pose particular health concerns. In-service diesel vehicles emit up to 50-80% more particulate matter than gasoline vehicles.

Containing noxious emissions

There are differences between the measures required to reduce the levels of nitrogen oxides and diesel particulate emissions from combustion engines and those required to achieve the high-priority objective, in the context of greenhouse gas emissions, of reducing motor vehicle fuel consumption. For example, the use of diesel engines with direct fuel injection can reduce fuel consumption by at least 20-30% (compared to normal diesel engines) – and sometimes close to 40% – without detracting from vehicle performance. However, direct injection diesel engines produce more NO_x (from 50-100% more), but less particulates than classical diesel engines.

Regulations which set more stringent standards for NO_x and particulate emissions have been agreed by the European Commission and will come into force by 2005-08. It is expected that the measures introduced by vehicle manufacturers to meet these standards will include: controlled exhaust gas recirculation (EGR) to reduce NO_x emissions; and particulate filters to trap and oxidise close to 95% of all of the particulates from diesel combustion. Some vehicle models sold in Europe from 2000 onwards were equipped with these systems.

Types of road vehicles

Road vehicles are commonly divided into three categories – passenger cars, duty vehicles and two-wheeled vehicles. Each category contributes in a different way to the level of CO_2 emissions. As the definitions of categories differ among research studies and across available statistics, how each category is specified should be carefully investigated before using comparative data based on each category. A description of the categories and how the definitions and content may differ is outlined below.

Passenger cars

In Europe, a high proportion of passenger cars (close to 90%) is comprised of four-door and two-door saloon vehicles. Between 10% and 12% are sport-utility vehicles or four-wheel-drive vehicles. Four-wheel-drive vehicles amounted to 3.2% of the passenger car fleet in 1998 in Europe, with values in individual countries ranging from 0.4% in Spain to 5.0% in the United Kingdom and 11% in Norway.

There are significant differences within passenger car markets in the proportions of gasoline and diesel engines sold in Europe. Diesel cars accounted for approximately 32% of the new cars sold in Europe during 2000 with considerable variation in proportions as follows: 62% in Austria, 53% in Spain, 49% in France and at the lower end, 14% in the United Kingdom, 13% in Denmark, 10% in Ireland, 9% in the Netherlands, Norway and Switzerland, and 6% in Sweden. These differences are explained in part by differences in the levels of taxes and charges: for example, annual vehicle taxes and charges, insurance, the prices of diesel and petrol fuel in each country all affect the proportions of sales.

The average engine power and capacity for all vehicles sold in Europe in 1998 were 69 kW and 1.67 litres, respectively.

In North America, and particularly in the United States, nearly 50% of new passenger cars comprised sport-utility vehicles, pick-ups and four-wheel-drives. In contrast to Europe, only a very small proportion of American cars have diesel engines and, with relatively low gasoline prices in the United States, vehicles are generally equipped with larger and more powerful engines.

Table 1 shows new registrations of passenger cars in 1998, 1999 and 2000 in major regions. In 2000, 38.5 million passenger cars were produced and registered in the world compared to 37.3 million in 1999 and 36 million in 1998.

Table 1. **New registrations of passenger cars, 1998, 1999 and 2000**
Million

	1998	1999	2000	Change 2000/1998
Europe (17 countries)	14.4	15.0	14.7	+2%
United States + Canada + Mexico	9.2	10.0	10.3	+12%
Japan + Korea	4.6	5.0	5.3	+15%
World	36	37.3	38.5	+7%

Source: CCFA, July 2001.

Duty vehicles

This category includes small duty vehicles constructed from large passenger cars (especially in Europe and Asia), light-duty vehicles (LDV), small trucks (5 to 10 tonnes), heavy trucks (20 to 50 tonnes) and buses. For small and light-duty vehicles, there are important definitional differences between Europe and North America. In Europe, some passenger cars are classified as duty vehicles if they are bought by companies and registered for business purposes. In the United States, a large portion of pick-ups are classified as LDVs; sales are high because fuel economy regulation currently imposed by the US Corporate Average Fuel Economy (CAFE) requirements is less stringent for LDVs than for passenger cars.

In Europe, all small and light-duty vehicles are powered by diesel engines; in the United States, a large proportion of such vehicles are powered by gasoline engines. Throughout the world, nearly all heavy trucks are powered by diesel engines.

Table 2 shows new registrations of duty vehicles in 1998, 1999 and 2000 in Europe, North America, Japan and Korea. In 2000, more than 18.6 million duty vehicles were produced and registered in the world, compared with 17.6 million in 1999 and 17 million in 1998.

Table 2. **New registrations of duty vehicles, 1998, 1999 and 2000**
Million

	1998	1999	2000	Change 2000/1998
Europe (17 countries)	2.0	2.2 *of which 250 000 were heavy trucks*	2.3 *of which 287 000 were heavy trucks*	+15%
United States + Canada + Mexico	8.7	9.8 *of which 300 000 were heavy trucks*	10.0 *of which 310 000 were heavy trucks*	+15%
Japan + Korea	2.4	2.1	2.1	–13%
World total	17	17.6	18.6	+9%

Source: CCFA, July 2001.

Two-wheeled vehicles

There is a large variety of two-wheeled vehicles. In several OECD countries, a large proportion of small two-wheeled vehicles are not registered, making it difficult to determine the total number of these vehicles in use. While two-wheeled vehicles have a significant impact on local pollution, their global impact in terms of GHG emissions is relatively minor.

Use of vehicles

With the help of new technologies, as well as a decrease in the size and weight of passenger cars, all road vehicles – and particularly passenger cars and heavy trucks – will be modified over the coming years to reduce their fuel consumption (gasoline and diesel) measured in litres/100 km. This will lead to reductions in the rate of CO_2 emissions from such vehicles.

Once the rate of CO_2 emissions (measured in grams/km) of individual motor vehicles is reduced, total CO_2 emissions from individual vehicles will depend, *inter alia*, on the yearly distance covered by each vehicle and where the travel is undertaken (*i.e.* under what conditions). Gains in vehicle fuel efficiency may be offset by increases in distances travelled.

For a given level of technological advance, the outlook for global emissions from road transport will therefore depend on some interdependent parameters:

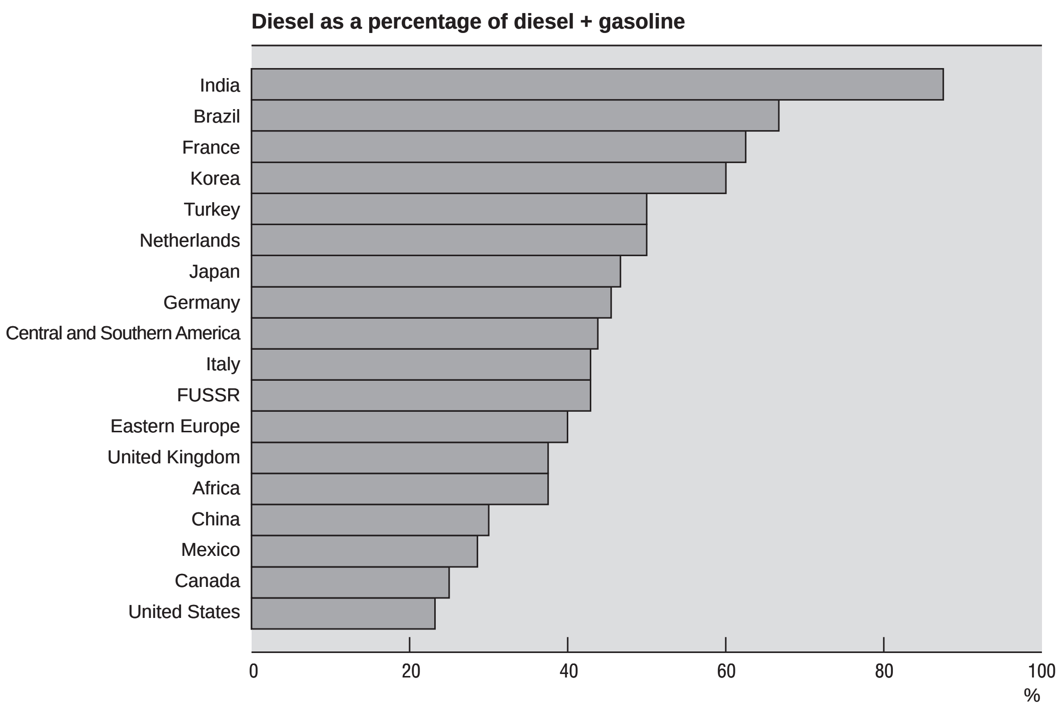
- Total distance travelled (*i.e.* whether or not there is an increase in vehicle kilometres travelled) and the conditions of travel.
- The share of freight transport by road as opposed to other travel modes. In this respect, despite popular belief, rail transport is often not a viable alternative to road transport, particularly for the increasing proportions of freight being transported over relatively short distances.
- The impact of current industry trends towards just-in-time production (with reduced stock holdings supplemented by just-in-time freight delivery).
- The energy efficiency of motor vehicle fleets.

In assessing the outlook for greenhouse gas emissions from road transport, it is necessary to consider the measures taken by OECD countries to reduce CO_2 emissions – and some of the results being achieved – including the cost-benefit balance, where it is possible to do so.

Proportion of diesel and petrol vehicles

US Energy Information Administration (US-EIA) data for various countries (Figure 2) show 1997 diesel use as a percentage of diesel plus gasoline. The data reveal that among developing and newly industrialised countries, India, Central and South America and Brazil have the highest diesel share, whereas among developed countries, France has the highest and the North American countries have the lowest diesel share. The overall world proportion of diesel use is 38% of total diesel and gasoline fuel use. Although diesel-powered cars are generally more expensive than gasoline-powered cars, the high percentage of diesel use in the developing countries (*e.g.* Central and South America and Brazil) is probably due in part to the price difference between diesel fuel and gasoline fuel and to the composition of the fleet. It is expected that the price difference between diesel-powered cars and gasoline-powered cars will decrease in the future, thus increasing the percentage of diesel being used compared to gasoline – if fuel price differentials are maintained.

Figure 2. **Shares of diesel and gasoline vehicles, 1997**
Million barrels of oil per day



Source: US Energy Information Administration (US-EIA).

Trends in CO_2 emissions

General trends in CO_2 emissions from fuel combustion

Worldwide emissions of CO_2 from fuel combustion have been rising steadily for many years. Total global emissions from all sectors increased by 62% from 14 141 million tonnes of CO_2 in 1971 to 22 818 million tonnes in 1999 (IEA, 2001). Over this period, emissions have risen in most sectors, with the largest increases evident in power generation and transport sectors. Transport is also the end-use sector with the lowest degree of flexibility, since it relies almost exclusively on petroleum. As reflected in Table 3, OECD countries currently account for slightly more than 50% of total worldwide CO_2 emissions.

In OECD countries, the share of CO_2 emissions from the transport sector was 19.4%, 24.9% and 27.1% in 1971, 1990 and 1999, respectively. Importantly, transport in OECD countries produces two-thirds of the CO_2 emissions from transport sectors worldwide. The worldwide share of total CO_2 emissions from the transport sector in 1971, 1990 and 1995 was 16.7%, 21.7% and 24.1%, respectively (IEA, 2000 and 2001) (Table 3).

Non-Annex I countries (developing and newly industrialised countries) use less energy in transport than do Annex I countries due to low levels of car ownership. However, it appears that significant increases in transport-related CO_2 emissions in these countries are likely over the next two decades.

Table 3. **CO_2 emissions from fuel combustion worldwide, 1990 and 1999**

Region	Total CO_2 emissions (billion tonnes of CO_2)			Transport share (%)	
	1990	1999	% change 1990-99	1990	1999
OECD	**11.01**	**12.15**	**+10.4%**	**24.9**	**27.1**
North America	5.55	6.37	+14.8%	29.4	30.5
Europe	3.93	3.89	–1.0%	20.1	24.1
Pacific	1.53	1.88	+23.3	20.6	22.2
Non-OECD	**9.06**	**9.91**	**+9.3%**	**12.3**	**14.6**
Non-OECD Europe	0.39	0.22	–41.9%	9.2	14.5
Former USSR	3.34	2.20	–34.2%	9.7	10.7
China	2.29	2.97	+29.8%	5.3	7.4
Non-OECD Asia (excl. China)	1.32	2.07	+56.9	16.6	18.5
Africa	0.54	0.66	+21.9%	19.0	18.8
Middle East	0.58	0.94	+63.4%	19.6	17.5
Latin America	0.60	0.84	+39.3%	33.4	34.4
World[1]	**20.7**	**22.82**	**+10.2%**	**21.7**	**24.1**

1. Includes CO_2 emissions from marine and aviation bunkers.
Source: IEA (2001).

The break-up of the USSR, the decline in the Russian supply of fossil fuels, and Russia's need for hard currency from energy exports caused significant declines in the energy supply to the Baltic States, Belarus and the Ukraine. The transition to free-market economies after 1992 was accompanied by a steep downturn in GDP, the collapse of traditional foreign markets, a slump in domestic production and decreased industrial output. Russia has experienced a decrease in total CO_2 emissions each year between 1992 and 1998 when it reached its lowest level of energy supply since 1992. In 1999 a slight increase of total CO_2 emissions was however observed. In contrast, China's contribution to CO_2 emissions grew strongly over the same period, from a relatively smaller base.

According to the IEA, global CO_2 emissions are projected to rise strongly in all regions, including the OECD, to a total of around 30 billion tonnes by 2010 and 36 billion tonnes by 2020. The IEA has reported that transport sector emissions worldwide are projected to rise by nearly 75% over the period 1997-2020 (IEA, 2000). These projections show that CO_2 emissions from the transport sector constitute a large and growing share of the increasing total global CO_2 emissions (see also Chapter 5).

Importance of transport modes

At present, the majority of the world's car fleet is located in the developed countries. The OECD North American region has the highest level of car ownership of all OECD regions. Levels in the OECD countries in Europe are variable. High demand for private cars is spreading rapidly to countries with transitional economies in Central and Eastern Europe and in the developing world (ECMT, 1997), escalating the potential increase in demand for fossil fuels. The share of emissions from the transport sector is closely connected to the growth in transport energy consumption and the increase in transport demand and reflects the increase in Gross Domestic Product (GDP).

Based on data supplied by 15 ECMT countries, ECMT (1999) calculated the share of modes in the freight market in selected years from 1970 to 1997. The report indicates that the market shares for rail, road and inland waterways in 1970 were 31.1%, 55.5% and 13.3%, respectively, whereas in 1997 the shares were 15.0%, 77.9% and 7.1%. These figures show that the freight transport market changed substantially over this period; the greater share of road transport has contributed to the increase in the overall share of CO_2 emissions coming from road transport.

Sources of emissions data

The data analysed and presented in this chapter were drawn principally from three main sources.

- The ECMT data were obtained from an in-depth 1996 survey of Member and Associate Member countries (ECMT, 1997). Countries are working to render their databases more disaggregated, reliable and sophisticated in terms of the information produced. Many data and methodological problems remain, however, and until improvements in these areas are made, comparative analyses will be difficult. Also, the Framework Convention on Climate Change (FCCC) experience indicates that many of the Annex I countries that have completed their communications have not followed the minimum documentation standards or provided explanations of methods and data according to the FCCC guidelines.
- The IEA data were drawn principally from a 2001 report (IEA, 2001). The IEA estimates of CO_2 emissions from fuel combustion are calculated using the IEA energy balances and default methods and emission factors from the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. There are many reasons why the IEA estimates may not be the same as the numbers that a country submits to the United Nations Framework Convention on Climate Change (UNFCCC), including, but not limited to: *i*) the IEA uses average emission factors; *ii*) the IEA does not have detailed information for the stored carbon calculation; and *iii*) the emissions inventories submitted to the UNFCCC may have been adjusted for electricity trade.
- A third source of data was provided by Member country's responses to a questionnaire circulated by the OECD Working Group that undertook this report. Relevant data and up-to-date information were obtained from 14 countries. Generally, the results of this study support the ECMT (1997) conclusion that data are not reported consistently. Nevertheless, the collected data do provide an overview of relevant emissions sources and trends.

How data are constructed

In accordance with international obligations, countries are requested to report CO_2 emissions from different sources. Reporting obligations are manifested as part of the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP), the UN Framework Convention on Climate Change (UNFCCC) and the EC Monitoring Mechanism of Community CO_2 and other Greenhouse Gas Emissions (93/389/EEC).

Under UNFCCC Guidelines, Parties prepare and periodically update national inventories that are accurate, complete, comparable and transparent. Inventory quality is an important issue when countries start to implement legally binding commitments. One way to assess inventory quality is to undertake comparisons of inventories, methodologies and input data. It is also possible to use the IEA CO_2 estimates for comparison with the National Communications to the UNFCCC Secretariat. In this way, problems in methods, input data or emission factors may become apparent. However, caution should be exercised in interpreting the results of any comparison since there are many reasons why IEA estimates may differ from a country's official submission. A recent comparison of the IEA estimates with the National Communications demonstrated that for most Annex I countries, the two calculations were within 5%.

Total yearly CO_2 emissions from road transport and emissions by vehicle type and fuel type are among the requested emissions data. In order to explain CO_2 emissions from road transport, it is helpful to subdivide the total CO_2 emissions by fuel type and vehicle type. The subdivision can be calculated with the aid of emission models. The European Environment Agency (EEA) and European Topic Centre on Air Emissions (ETC/AE) encourage and assist countries to report CO_2 emissions and other gaseous emissions in a consistent way with the aid of emission models (EEA, 1997).

The emissions forecasting models developed at national levels are often based on the fact that CO_2 emissions from road transport are closely correlated with fuel consumption. In fact, the CO_2 emissions depend on the carbon content of the fuels (Bang *et al.*, 1999). Hence, good estimates of the emissions Q (g CO_2) from a vehicle can be calculated as the product of an emission factor q (g CO_2/g fuel) and the amount of fuel consumed, m (g fuel). The average carbon content of some fuel types is given in Table 4.

Table 4. **Emission factors for selected fuel types**
g CO2/g fuel

Petrol	3.13
Diesel	3.17
LPG (propane and butane)	3.00
CNG (compressed natural gas)	2.75

Source: Bang *et al.* (1999, p. 21).

National transport share of CO_2 emissions

The national transport share (%) of CO_2 emissions from fuel combustion for the countries included in the study is in the 8% to 38% range. The CO_2 emissions not ascribed to transportation come from stationary sources (*e.g.* residential, burning of garbage) and industrial processes. The variation can be explained by the different economic bases in the countries and the geographical and demographic differences.

It is noted that the large national transport share of CO_2 emissions in Switzerland is due to the lack of heavy industry and to the hydraulic production of electricity. Moreover, the difference between the total amount of fuel sold and combusted in Switzerland is not negligible, and is by definition interpreted as "fuel tourism" or "bunker". This assumption is justified on the grounds of a significant price difference between Switzerland and its neighbours (with gasoline being cheaper and diesel fuel being more expensive); the net effect is export (FOEFL, 1997). The low gasoline price has the effect that people from Northern Italy and France come to Switzerland to fill up with gasoline, while the opposite occurs with diesel, with Swiss trucks filling up in France.

India, one country not included in the study, has had a large growth in transport-related CO_2 emissions. The total road network in India increased by about 21% from 1985 to 1991. Based on TERI (1996), transport-derived CO_2 emissions from combustion of petroleum products accounted for approximately 10% of the national CO_2 emissions from fossil fuel combustion in India in 1991/92.

CO_2 *emissions from road transport*

Road transport contributes between 55% and 99% of CO_2 emissions from transport. The data reveal that most countries have a relatively constant relationship between CO_2 emissions from road transport and other transport modes. However, a few countries show different trends. As a result of the break-up of the Soviet Union and the reduction in levels of economic activity in some former parts of the Soviet Union, transport emissions have fallen. A shift towards road transport has meant, in several cases, that the road transport share of overall emissions has increased, pointing to even greater falls in emissions from other transport modes. An increasing trend in the share of road transport as compared to all transport is found in Poland, Lithuania, Latvia and Russia, where the increases were from 59% to 70% (1990-94), 77.5% to 84.6% (1990-93), 78.5% to 90% (1990-95) and 62% to 73% (1990-95), respectively. For all of these countries except Poland, there was nevertheless a decrease in CO_2 emissions from road transport and an even larger reduction in CO_2 emissions from other transport modes. The establishment of several small states with a new economic base reduced haulage of heavy raw materials, oil and coal, which were the dominant goods transported by rail in these countries in earlier years.

For the sake of simplicity and ease of presentation, the trends in CO_2 emissions from road transport over time were examined for groups of countries (Groups 1-6) based on their levels of CO_2 emissions from fuel combustion in 1999 (Figure 3). Group 1 represents the lowest level of emitted CO_2 at 0 to 8 million tonnes. Group 6 countries emitted over 200 million tonnes from the road transport sector. As can be seen from the charts and from Table 5, CO_2 emissions from road transport increased in most countries over the 1990-99 period.

Over the 1990-1999 period, the overall growth rate was 18.6 % for the EU countries, 22.7 % for OECD countries, 35.5 % for non-OECD countries, and 26.3 % for the whole word (see Appendix B for the complete data set). Of the 34 countries shown in Table 5 (countries of the former USSR, being considered as one country), 16 showed increases of over 20 %. Three countries showed decreases over this period: Bulgaria, Romania and the former USSR. In these three countries, the declines can be traced to downturns in economic activity.

From a global perspective, however, the number of countries showing increases or decreases is less significant than the aggregate emissions produced by those nations. In this regard, the countries in Groups 5 and 6 have a disproportionate impact on the total emissions. Between 1990 and 1999, their road transport emitted an average of 2.2 billions tons of CO_2 emissions per year, *i.e.* 60 % of the average contribution for all countries worldwide.

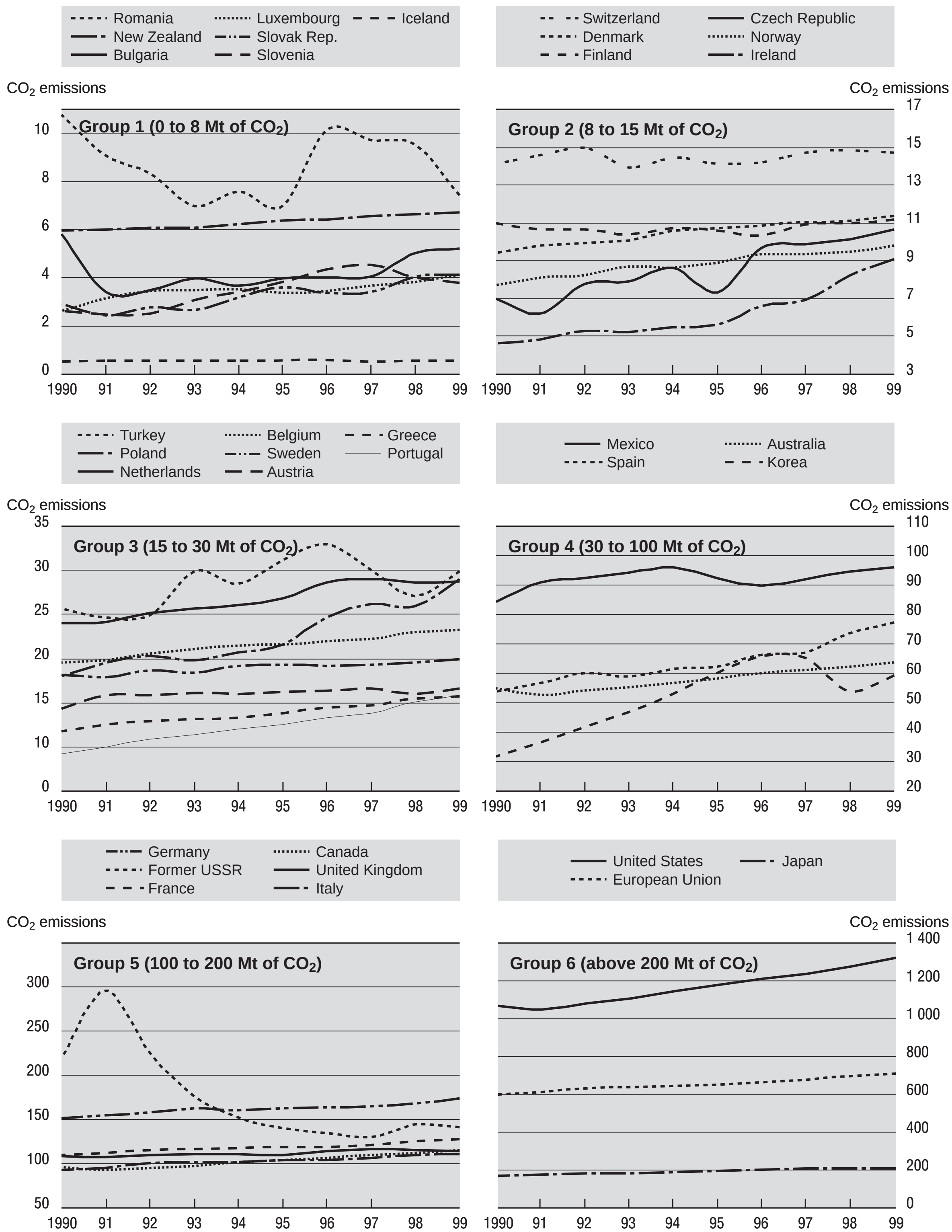
Perspectives in respect to the Kyoto Protocol targets

There is no requirement under the Kyoto Protocol for the road transport sector in each country to reduce emissions commensurate with each nation's target as a whole under the Kyoto Protocol, *e.g.* that road transport achieve reductions of 7% below 1990 levels if the nation's overall target is 7%. However, transport sector performance relative to each nation's economy-wide target serves as a benchmark for assessing relative contributions. Recent increases in emissions by the road transport sector of member nations, taken as a whole, will make it very difficult for the transport sector to contribute to each country's economy-wide CO_2 targets.

Contribution of road freight transport to CO_2 emissions

Another area of significant policy and research interest is the contribution of road freight transport to CO_2 emissions. Based on the data provided by the delegates of the OECD Working Group, the contribution of road freight transport to CO_2 emissions (compared to the overall CO_2 emissions from road transport) ranges from 13% to 40% depending on the country. Unfortunately, there were uncertainties as to how different countries classify such vehicles. Hence, it is very difficult to consistently compare CO_2 emissions from freight transport across different countries. The same classification problem occurs in attempting to disaggregate CO_2 emissions from road transport into CO_2 emissions from passenger transport and freight transport. One fairly obvious reason for this is that a large group of vehicles can be used for both passenger and freight transport. Inspection of data from ECMT (1997) and data collected by the Working Group covering the period 1990-97 indicate that some 20-30% of CO_2 emissions from road transport may be attributed to freight transport in the western EU Member States, Switzerland, Norway, Australia, Canada and the United States.

Figure 3. **CO_2 emissions from fuel combustion by road transport, 1990-99**



Source: IEA.

Table 5. **CO_2 emissions from road transport**

	Evolution in CO_2 emissions from transport between the base year and 1999[1]	Evolution in CO_2 emissions from road transport between the base year and 1999[1]	Road transport share of CO_2 emissions compared to transport	National CO_2 emissions target under the Kyoto Protocol (%) compared to the base year level[1]
Australia	+16.9%	+16.3%	88%	8.0%
Austria	+16.4%	+15.4%	95%	–13.0%
Belgium	+21.2%	+18.8%	94%	–7.5%
Bulgaria	–17.4%	–24.3%	92%	–8.0%
Canada	+21.8%	+20.2%	76%	–6.0%
Czech Republic	+57.6%	+51.9%	93%	–8.0%
Denmark	+6.6%	+20.6%	91%	–21.0%
Finland	+4.2%	+2.2%	91%	0.0%
France	+17.6%	+16.9%	94%	0.0%
Germany	+11.5%	+14.9%	97%	–21.0%
Greece	+29.0%	+34.8%	80%	25.0%
Hungary	+10.0%	+22.5%	96%	–6.0%
Iceland	0.0%	+7.5%	92%	10.0%
Ireland	+94.2%	+95.0%	94%	13.0%
Italy	+17.5%	+19.1%	98%	–6.5%
Japan	+25.6%	+24.6%	89%	–6.0%
Korea	+87.2%	+85.6%	73%	
Luxembourg	+58.5%	+56.3%	98%	–28.0%
Mexico	+13.4%	+14.3%	98%	
Netherlands	+18.2%	+19.4%	92%	–6.0%
New Zealand	+36.2%	+12.9%	55%	0.0%
Norway	+18.6%	+26.6%	75%	1.0%
Poland	+23.4%	+40.1%	97%	–6.0%
Portugal	+70.8%	+71.7%	94%	27.0%
Romania	–16.5%	–18.5%	84%	–8.0%
Slovak Republic	+43.5%	+41.1%	98%	–8.0%
Slovenia	+64.1%	+45.5%	99%	–8.0%
Spain	+39.9%	+44.3%	86%	15.0%
Sweden	+8.4%	+10.1%	90%	4.0%
Switzerland	+3.1%	+4.0%	97%	–8.0%
Turkey	+19.5%	+16.7%	89%	
United Kingdom	+7.5%	5.4%	87%	–12.5%
United States	+18.9%	23.8%	83%	–7.0%
Former USSR	–27.3%	–35.9%	60%	0.0% for Russia and Ukraine, –8.0% for Estonia, Latvia,Lithuania
Region				
15 EU countries	**17.6%**	**18.6%**	**93%**	**–8.0%**
OECD countries	**+20.3**	**+22.7%**	**86%**	
Non-OECD countries	**29.5**	**+35.5%**	**84%**	
World	**22.7**	**+26.3%**	**74%**[2]	

1. The base year is 1990 for all countries, except Bulgaria (1988), Poland (1988), Hungary (average of 1985-87) and Romania (1989).
2. Includes CO_2 emissions from marine and aviation bunkers

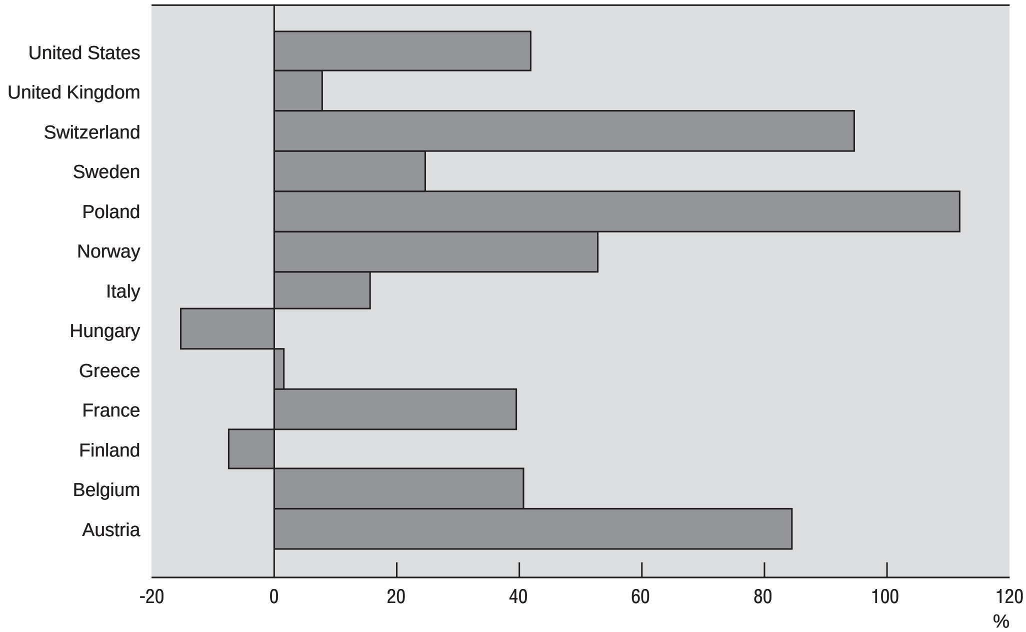
Source: IEA (2001).

Figure 4 shows percentage changes in freight transport by road (in thousand million tonne kilometres) over the period 1990-97. The range is –7% (Finland) to 112% (Poland), with an overall 37% increase from 1990-97 for the countries shown.

Conclusions

- Total CO_2 emissions from all sources are growing in all OECD countries and are increasing even more rapidly in developing countries, particularly the newly industrialised countries (*e.g.* India).
- The transport share of overall CO_2 emissions increased on a global basis over the period 1990 to 1999.

Figure 4. **Evolution of road freight transport, 1990-97**
Percentage change in tonne kilometres



Source: IRTAD, ECMT (1999); US Bureau of Transportation Statistics (1999).

- While comparable data are not available for the OECD countries, the freight share of CO_2 emissions is increasing relative to the passenger share.

The Kyoto Protocol seeks an average 5.2% reduction of greenhouse gases compared to 1990 levels by Annex I countries on an economy-wide basis. The trends outlined above indicate that it would be extremely challenging for the road transport sector in OECD countries to achieve substantial reductions of its CO_2 emissions by 2012 that could contribute proportionately to economy-wide CO_2 reductions.

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Chapter 3

POLICIES AND MEASURES TO REDUCE CO_2 EMISSIONS FROM TRANSPORT

This chapter examines the types of policies and measures being implemented by the international community and by OECD countries aimed at reducing CO_2 emissions from the transport sector. The chapter does not provide a comprehensive assessment of individual countries' strategies but aims to illustrate the range and types of measures implemented across countries.

International measures to reduce emissions of greenhouse gases

The UN Framework and the Kyoto Protocol – National legislation

United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) is an international convention that addresses issues related to the emission of greenhouse gases (GHGs). The ultimate objective of the UNFCCC is to stabilise GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

The UNFCCC was adopted in May 1992, and as of September 2000 had been ratified by 186 parties. Seven Conferences of the Parties have been held, the most recent of which took place in Marrakech (Morocco) in November 2001.

At the Third Conference of the Parties held in Kyoto in December 1997, the Kyoto Protocol was adopted (see below). To implement the Protocol, issues are currently being discussed, particularly with regard to a framework for meeting such goals as GHG emissions reductions by developing nations and designing and facilitating "clean development mechanisms". The countries that have ratified the UNFCCC are responsible for:

- Developing national inventories of emissions of all GHGs.
- Formulating, implementing, publishing and updating national programmes containing measures to mitigate climate change.
- Promoting and co-operating in the development, application and diffusion of technologies, practices and processes that control, reduce, or prevent anthropogenic emissions of GHGs in all relevant sectors.

Kyoto Protocol

The Kyoto Protocol, which established GHG emissions reduction goals for parties included in Annex I to the Convention, was adopted at the Third Conference of Parties to the UNFCCC held in Kyoto in December 1997. 84 parties signed the Kyoto Protocol among which 26 had ratified or approved it as of December 2001. In addition, 20 additional parties have since acceded to the Kyoto Protocol (for more information, see: *http://unfccc.int/resource/convkp.html*).

The Kyoto Protocol assigns the following responsibilities to the parties:

- To ensure that their GHG emissions do not exceed their assigned levels in the period 2008-12.

- To make demonstrable progress in achieving their commitments under the Kyoto Protocol by 2005.
- To implement and/or elaborate policies and measures in accordance with their national circumstances in achieving their quantified emission limitation and reduction commitments under the Kyoto Protocol.

Under the Kyoto Protocol, all involved countries are committed to policies that seek a global reduction of emissions of GHG, particularly CO_2 and CH4. Targets have been set for many countries that represent percentage reductions (but for some countries no change or small increases) in their emissions of CO_2 and CO_2 equivalent gases relative to their 1990 levels.

Within each country, all sectors using fossil fuels are involved, including industry, energy and transport. A first assessment indicates that transport is responsible for between 8-40% of national CO_2 emissions, depending on the country.

Road transport is responsible for 10-35% of total emissions. Since the signing of the Kyoto Protocol, several countries have established policies aimed at limiting these emissions in the road transport sector, with the measures being developed generally concerning both vehicle technology and vehicle use.

National legislation targeting the prevention of global warming

Member countries participating in this study have enacted various legislative acts and developed a range of policies to prevent global warming. In most countries, significant fuel taxes, which have existed for many years, operate to encourage more efficient road transport and therefore to restrain CO_2 emissions. In addition, each country's laws include those established for the express purpose of reducing GHGs. Countries regard the reductions of GHGs indirectly resulting from all of these laws as part of their global warming prevention policies.

Direct Measures

Those participating countries that have enacted legislation for the express purpose of preventing global warming include France, Japan, Norway and Switzerland. The French, Japanese and Swiss laws establish a national framework for dealing with global warming, while the Norwegian legislation aims to reduce CO_2 emissions through the introduction of a CO_2 tax. In summary, the legislative developments include:

- *France*: Law on Air Quality and Energy Consumption.
- *Japan*: Law concerning the Promotion of Measures to Cope with Global Warming; Basic Policy on Measures to Cope with Global Warming.
- *Norway*: CO_2 tax.
- *Switzerland*: The Environmental Protection Law.

Indirect Measures

Further legislation and policies have been developed which aim at producing energy-saving automobiles and improving road traffic flow, thus reducing the effects of GHGs. Initiatives include:

- *Energy-saving automobiles*. For example, Canada [Vehicle Emissions Regulation]; Japan [Energy Conservation Act]; Netherlands [Variabilisation of Excises in order to Encourage the Use of Fuels with Low CO_2 Emissions – Enforcement of Speed Limits]; Norway [Purchase Tax on Cars]; United Kingdom [Vehicle Excise Duty differentiated by CO_2 emissions]; United States [Corporate Average Fuel Economy (CAFE) – Gas Guzzler Tax – the Alternative Motor Fuels Act].
- *Fuel taxes*, as in Australia, Korea, Switzerland, the United Kingdom (the UK Fuel Duty Escalator – the Chancellor announced in his 1999 pre-Budget Report that the appropriate level of fuel duties would be set on a budget by budget basis, which remains current policy), and other countries.
- *Measures to improve road traffic flow*, such as in Australia, Japan, Korea, Czech Republic, The Netherlands, United Kingdom, United States.

Catalogue of existing measures

Improvement of fuel efficiency

National legislation

Several countries have introduced legislation in an attempt to improve vehicle fuel efficiency. One example is the Corporate Average Fuel Economy standards programme (CAFE) in the United States. This requires car manufacturers producing cars and light trucks in the United States to meet a fuel economy standard for new vehicles on a fleet average basis. The Energy Policy and Conservation Act was passed by Congress in 1975 and requires car manufacturers to meet fuel economy standards that was initiated at 18 miles per gallon (13.1 litres per 100 km) in 1978, increasing to 27.5 mpg (8.61 l/100 km) by 1985. Standards for trucks were set administratively by the Department for Transportation.

Failure to meet the standards resulted in a fine that amounted to USD 50 per car sold for each mile per gallon (mpg) below the standards. Manufacturers could earn credits by exceeding the standards and the credits could be used to offset a shortfall through a three-year carry-forward and carry-back provision. Between 1986 and 1989, standards for cars were rolled back due to a collapse in oil prices which resulted in reduced demand for more fuel-efficient cars. Standards for light trucks have been set at around 20.5 ± 0.5 mpg (11.5 ± 0.3 l/100km) for the last 15 years.

In 1999, Japan revised its Law Regarding the Rational Use of Energy, increasing the stringency of efficiency standards for gasoline-powered automobiles and light trucks, and expanding the law to cover diesel-powered vehicles. It has been estimated that the standards will reduce the average CO_2 emissions of new gasoline vehicles (cars and trucks) by about 21% by 2010 and that of diesel vehicles by about 13% by 2005. Failure to reach the efficiency standards can result in fines being levied.

Voluntary agreements

The European Union's CO_2 from Cars Strategy aims to reduce average CO_2 emissions from new passenger cars to 140 g/km by 2005 or 2010 at the latest. This represents a cut of around one-third in the rate of emissions from new passenger cars, measured in terms of official test cycles. The bulk of this reduction will be delivered through the voluntary agreements, secured between the European Commission and European, Japanese and Korean car manufacturers, which will reduce average CO_2 emissions to 140 g/km by 2008/09 (a cut of around 25%). It should, however, be noted that the European Commission strongly recommends that new car models with average CO_2 emissions inferior or equal to 120 g/km be marketed by 2005. The Commission is setting up a monitoring scheme to provide objective information on CO_2 emissions from passenger cars to enable the agreements to be monitored and reviewed at the interim target date of 2003/04.

Other examples of voluntary agreements include the agreement between the Italian Environment Ministry and FIAT. In 1997, the FIAT Group undertook to reduce average emissions from its new car fleet to 145 g/km by 2005 and 136 g/km by 2010. The agreement also seeks to promote the development and use of vehicles based on alternative energies and new architectures (electric, hybrid, natural gas, biofuel) with a minimum environmental impact, as well as to ensure that older cars will not burden the environment.

Fiscal measures

Many countries have fiscal measures in place to encourage consumers to purchase more fuel-efficient cars, to use their cars less and to drive in a more fuel-efficient manner.

The United Kingdom introduced a graduated annual registration tax (Vehicle Excise Duty) for new cars from March 2001. Cars are categorised into one of four bands based on their rate of CO_2 emissions. Cars using cleaner fuels and alternative fuel technology (initially those run on road fuel gas, bi-fuel, dual fuel and hybrids) will receive an extra discount. Within each band, there is also a supplement for diesel cars to reflect their higher emissions of particulates and other pollutants that damage local air quality.

Existing cars will be separated into two groups depending on engine size (as a rough proxy for CO_2 emissions). Those with an engine size of 1 549 cc or less will pay a lower rate.

Other measures

Canada has an EnerGuide Labelling Programme developed jointly by government and industry. Under this programme, automobile manufacturers voluntarily affix fuel consumption labels to new vehicles offered for sale. The label will show the estimated fuel consumption of the vehicle as well as the fuel cost for 20 000 km. Consumers will be able to compare the average city and highway fuel consumption ratings of all new cars, vans and light duty trucks and also to assess the potential economic and environmental savings that can be realised by choosing to purchase one vehicle over another.

This initiative operates in conjunction with the Fuel Consumption Guide that provides vehicle buyers with fuel efficiency information for all new vehicles (passenger cars and SUVs).

Summary of fuel efficiency measures

Table 6 contains a range of measures aimed at improving the fuel consumption of vehicles.

Table 6. **Measures for improving the fuel consumption of vehicles**

	Setting fuel consumption standards	Tax based on fuel consumption	Vehicle fleet renewal programme	Labelling programme
Australia	Environmental Strategy for the Motor Vehicle Industry			Environmental Strategy for the Motor Vehicle Industry
Canada	Motor Vehicle Fuel Efficiency Initiative	Excise tax on "high-energy consuming motor vehicles"	AutoSmart and FleetSmart programmes	EnerGuide labelling programme
Czech Republic	Pollutant limits for new road motor vehicles, etc.			
France	EC/ACEA voluntary agreement Technical control of the emissions of lorries and private cars, etc.		Scrappage programme (1993-1995)	
Hungary		Restriction of the importation of used vehicles by customs and tax regulations	National scrappage and replacement programme	
Italy	EC/ACEA voluntary agreement Voluntary agreement with FIAT	Luxury tax according to engine size	Initiatives to increase efficiency of car fleet, etc.	
Japan	Energy conservation act			
Korea	Fuel efficiency targets of vehicles			Classification of vehicle fuel efficiency
Netherlands	EC/ACEA voluntary agreement			Fuel-efficiency labelling system.
Norway		CO_2 tax on gasoline and diesel. Tax based on vehicle weight, cylinder volume and horse power is included in the purchase price on new cars	National scrappage programme (1996)	
Switzerland	Reduction of specific fuel consumption of road vehicles	CO_2 law, CO_2 tax has to be implemented if target (–8% 1990-2010) is missed		In preparation
United Kingdom	EC/ACEA voluntary agreement	Graduated vehicle excise duty		Consumer information
United States	Corporate average fuel efficiency standards (CAFE)	"Gas-guzzler" tax		

Traffic demand management

Improvement of road traffic flow

A number of policies have been implemented as part of the broad implementation of Intelligent Transport Systems to smooth traffic flow and reduce congestion. Because CO_2 emissions tend to increase at lower speeds and particularly with stop-start-driving, these policies can also help to reduce CO_2 emissions:

Many cities in the United States have adopted traffic signal synchronisation and control. The fuel consumption effects have been assessed with a simulation model that uses travel time, number of stops and observations in laboratories to evaluate fuel consumption. In California, it is estimated that traffic signal revisions at 3 172 locations have reduced fuel consumption by 8.6%.

However, a similar experiment with traffic signal synchronisation in Niort, France, produced a rather different result. Although the average speed increased, this led to an increase in traffic of almost 7%, and resulted in an almost 6% increase in global fuel consumption. Reasons for differences in modelling results are discussed in greater detail in Chapter 4.

At one congested location in Tokyo, Japan, an infrastructure project was conducted at the location where railway tracks and trunk roads intersect. As a result, traffic speed more than doubled, with an estimated CO_2 reduction of approximately 12 000 tonnes of CO_2 per year.

A number of other measures aimed at improving traffic flow have been introduced by several countries, including:

- Alleviating traffic congestion during peak hours (for example, by staggering work hours).
- Electronic toll collection.

Reduction in transport demand

Taxation plays an important role in countries' strategies to reduce the demand for transport. For example, in January 2000, the French Government announced a new programme to reduce CO_2 emissions from transport. One element of this was a new ecotax on fuels that will amount to EUR 0.0534/litre by 2010.

The national CO_2 tax introduced by Norway in 1991 covers almost 60% of total CO_2 emissions. Sectors not covered by the tax include international sea traffic and domestic goods transport. According to Norwegian estimates, for the period 1987-93, CO_2 emissions from mobile sources of households were reduced by 2%-3% per year.

Some limited applications of road pricing or congestion charging have also been introduced in a number of cities. For instance, the introduction of congestion charging in Korea (in Namsan Tunnels 1 and 3 in Seoul) is estimated to have reduced traffic volume by nearly 11% over the two years since its introduction, and to have increased traffic speed by around 50% over the same period.

Switch in transport modes

A number of measures have been introduced to encourage a switch to public transport by increasing the frequency, convenience and travel speed of public transport. The CO_2 benefits of such policies depend on the fuel efficiency of buses and trains relative to cars and, in particular, on the occupancy rates of the various modes. Lyon, France, has a number of targets to reverse the growth in car usage. For example, it has announced the following ten-year targets:

- Reduce the use of private cars by 3%.
- Increase the use of public transport (by 2%) and cycling (by 1%).
- Reduce noise levels.
- Reduce road crashes by up to 40%.

To achieve these targets, Lyon is adopting the following measures:

- Developing new tramlines.
- Improving train services.
- Creating a network of cycle paths.
- Controlling parking and reducing the capacity of the main streets.
- Developing "quiet zones".
- Keeping transit traffic out of the city centre.

Several countries have introduced Park-and-Ride systems. In Japan, an experiment was conducted in Osaka with 300 parking lots located outside the city centre. CO_2 emissions reductions were estimated to be about 1 400 kg of CO_2 per month. Results showed that the park-and-ride option reduced the mileage of those who had previously commuted by car, but increased the mileage of those who had formerly commuted by train and by bus, but who chose to drive to the park-and-ride station.

For detailed descriptions on traffic management measures, see OECD (2002).

Alternative fuels and technologies

A number of alternative fuels and technologies are being developed that have the potential to significantly reduce CO_2 emissions and local air pollutants. Several countries have incentives in place to encourage the uptake of such vehicles. These include:

- Fiscal incentives for the purchase of such vehicles.
- Support for the research and technological development of alternatively powered vehicles.
- Obligations to purchase alternatively powered-vehicles.

Canada has a programme aimed at promoting the development and use of alternative transportation fuels such as propane, natural gas, methanol, ethanol, electricity and hydrogen. Natural Resource Canada works with the alternative transportation fuel industry and major automobile manufacturers in Canada to promote Alternate Transport Fuels (ATFs). Activities include the development and promotion of ATF vehicles, vehicle conversion kits and refuelling equipment, regional market demonstration of ATF applications, a Web site, publications and other communication activities. The activities are geared towards demonstrating cost-effective applications.

Since 1983, Natural Resource Canada grants for motor vehicle conversions to natural gas resulted in a total of more than 35 000 conversions by 1994, of which as many as 25 000 are still on the road. In addition, Natural Resource Canada grants for natural gas refuelling stations initiated in 1983 resulted in a total of 135 stations by 1995. Substantial support for natural gas as an ATF ended in March 1997.

There are a number of measures in Japan to encourage the introduction of alternative technologies and fuels. These include purchase subsidies and investment in refuelling infrastructure. As a result, around 37 500 hybrid vehicles had been sold in Japan as of March 2000.

In 1993, the United States Government and the Chief Executive Officers of the three major domestic vehicle manufacturers announced the Partnership for a New Generation of Vehicles (PNGV). The PNGV is a voluntary, co-operative partnership between the government and the automobile industry. The PNGV has set a goal to develop vehicles that can achieve up to three times the fuel efficiency of comparable 1994 family sedans (a goal of around 80 mpg or 2.9 l/100 km) by 2004 without compromising safety, performance and affordability.

The United States has recently announced an expansion of PNGV to include light trucks. The goal of the truck project is to make the most popular vehicles more environmentally-friendly. Vehicle manufacturers would achieve this goal by producing small trucks using a combination of electric and diesel engines that, according to some estimates, can get up to 50 mpg (4.7 l/100 km).

The greenhouse gas reductions goals from utilisation of PNGV technologies are 12 MtC equivalent (or 44 Mt CO_2 equivalent) in 2010 and 30 MtC equivalent (or 110 Mt CO_2 equivalent) in 2020. Expectations vary and depend on programme funding as well as attribution of efficiency gains external to PNGV. To date, the government and industry have spent approximately USD 6.1 billion on PNGV initiatives, shared equally between the two parties.

Combinations of measures

Most countries have adopted a combination of the above policies and measures as part of a comprehensive strategy to reduce CO_2 emissions. The United Kingdom has adopted a combination of fiscal and labelling measures to back up the European Commission voluntary agreements, as well as providing support for alternative fuels and technologies.

- *Voluntary agreements* between the European Commission and European, Japanese and Korean car manufacturers.
- *Graduated Vehicle Excise Duty* (described in Chapter 3 above).
- *Company Car Taxation* – cars provided to employees by companies for private use are currently taxed on the basis of the car's price, as if the benefit of the car were received in income. Beginning in April 2002, the tax charge will be based on a percentage of the car's price graduated according to the level of the car's CO_2 emissions. The charge will increase from 15% of the car's price for cars emitting 165 g/km in 1% steps for each additional 5 g/km over 165 g/km. Diesel cars will be subjected to a 3% supplement in recognition of their higher emissions of pollutants that damage air quality.
- *Consumer information* – this will consist of a combination of the labelling directive set up by the European Commission to introduce compulsory fuel economy labelling on all new cars as well as the UK advertising campaign "Are You Doing Your Bit?".
- *Powershift Programme* – this is a government-funded programme run by the Energy Saving Trust to help encourage the development of a market for clean fuel vehicles in the United Kingdom. The programme provides grants to compensate for the higher cost of buying cleaner fuels or electric vehicles. The next phase of the programme has started to consider more closely the environmental benefits of hybrid and fuel cell technology.
- *Energy Efficiency Best Practice Programme* (EEBPP) – this programme is aimed at promoting greater fuel efficiency within the road haulage and bus industries. A recent survey has shown that companies using the advice of the EEBPP have saved 25% more fuel compared to companies that have not.

Table 7 gives details of where further information on individual countries' climate change strategies can be found.

Conclusions

A wide range of policies and measures are being pursued to reduce CO_2 emissions from road transport in OECD countries. There is varying emphasis on the different components of the transport system. However, many countries have similar approaches to the policies and measures expected to produce the largest reductions in CO_2 emissions:

- Fiscal measures (*e.g.*, fuel taxes, vehicle taxes) and other incentives to encourage the purchase of more fuel-efficient vehicles.
- Voluntary agreements with vehicle manufacturers to reduce the fuel consumption of new vehicles.
- Usage charges to encourage reduction in CO_2 emissions through more efficient use of transport vehicles.

The approaches taken by many countries show that there is support for packages of policy measures which address issues on a national, state and local basis and provide consistent incentives to the transport industry and to transport users to pursue more sustainable transport activity. However,

Table 7. **Strategy documents for climate change action plans**

	Strategy document	Web site
Australia	The National Greenhouse Strategy (1998)	*www.greenhouse.gov.au/pubs/ngs/ngs.html*
Canada	Canada's National Action Programme on Climate Change (NAPCC)	*www.ec.gc.ca/climate/resource/cnapcc/indexe.html*
Czech Republic	The State Environmental Policy of the Czech Republic, Programme of Stabilisation and Reduction of CO_2 Emissions from Transport in the Czech Republic	
France	New French Programme Against Greenhouse Gases	*www.effet-de-serre.gouv.fr*
Japan	Guideline of Measures to Prevent Global Warming	
Hungary	The National Energy Saving and Energy Efficiency Improvement Programme	
Netherlands	The Climate Change Implementation Plan	
Norway	Norwegian Climate Change Policy, Ministry of the Environment, April 1999	
Switzerland	Infrastructure and environmental policy based on sustainable development. The Environmental Legislative Framework. CO_2 law/Strategy DETEC (Federal Department of Environment, Transport, Energy and Communications)	*www.uvek.admin.ch*
United Kingdom	Climate Change: The UK Programme, November 2000	*www.environment.dtlr.gov.uk/climatechange/cm4913/index.htm*
United States	The Climate Change Action Plan (CCAP), October 1993 Global Climate Change Policy Book, February 2002	*www.whitehouse.gov/news/releases/2002/02/climatechange.html*

there are relatively few examples of national policies and measures taken by national governments to reinforce actions being taken by industry and individuals.

While there are *ex post* evaluations of local experiments, given the different policy frameworks and circumstances in different geographic regions, countries and cities, it is clear that what works for one country/city will not necessarily work for another.

It is also clear that the majority of the examples provided by Member countries are aimed at reducing CO_2 emissions from passenger cars. Analysis of the relative contributions from passenger and freight transport and their respective growth projections indicates that freight is a very important sector that will require the implementation of specific measures to reduce the forecast contribution of freight to global emissions (as shown in Chapter 2).

REFERENCE

OECD (2002),
Road Travel Demand: Meeting the Challenge, OECD, Paris.

Chapter 4

ASSESSMENT AND MODELLING METHODS: AN EVALUATION FRAMEWORK

This chapter reviews the key issues associated with the assessment and evaluation of policies and measures designed to reduce CO_2 emissions. The first part addresses the practical and theoretical issues that need to be taken into account when assessing the impact of CO_2 reduction policies. It is split into three sections:

- *Limits and uncertainties*, which covers some of the sources of uncertainty associated with trying to model complex real-life situations, for example data constraints.
- *Cross-cutting issues*, which examines at some key methodological issues (the rebound effect and double counting) that need to be incorporated into the assessment framework.
- *Indicators*, which considers what should be measured in a broader sense, including a range of possible non-CO_2 impacts that might be useful to include in the evaluation.

The second part of the chapter explores how a number of OECD countries have put this theoretical framework into practice by examining the range of modelling techniques used to assess the impact of policies to reduce CO_2 emissions. It gives a broad overview of the range of models and techniques used. Whilst sophisticated modelling of the potential impact of policies is often carried out, this project has identified very little consistent *ex post* evaluation of policies, partly because of the difficulties associated with isolating particular impacts and also the cost involved. However, *ex post* evaluation should be a crucial part of the continuing drive to develop successful and cost effective policies and measures. The chapter concludes by considering the missing elements from current analyses and addresses the continuing problem of data constraints as well as the inclusion of life-cycle impacts.

Assessing the impact of CO_2 reduction measures: a framework

Limits and uncertainties

All evaluation models used to estimate the impact of policies and measures on the amount of CO_2 emissions involve many uncertainties. The sources of these uncertainties include:

- Complexities involved in the construction of an evaluation model.
- Constraints attributed to the availability and reliability of data.
- Limitations in quantifying the degree of regulatory enforcement and the extent of adoption by the various governments.
- Unpredictability of future technological advancement.

Complexities involved in the construction of evaluation models

It is impossible to include all the existing factors that possibly influence the amount of CO_2 emitted from transport in an evaluation model. Any evaluation model, therefore, simplifies reality. For example, the introduction of off-peak commuting results in a reduction of CO_2 emissions through a complex mechanism involving various interdependent transactions. It is impossible to build an evaluation model which accurately reflects the actual changes such as: people's commuting behaviour, traffic volume measured on an hourly basis, the nature of traffic flow within an overall transport network, and incidences and conditions of traffic congestion, average travel speed. Because of the limitations in simulating reality, any such model must rely on many assumptions.

Constraints attributed to the availability and reliability of data

All analysis or evaluation is bounded by data availability; the data reliability and quality vary depending on how and when the information is collected. For example, the location, time period and frequency of observations all affect the outcome of an evaluation since traffic volume, travel speed, and length of traffic congestion differ each day. However, it is common practice to collect traffic data from a particular section of road on one particular day. This approach may produce inaccuracies if annual traffic volume or traffic volume within a larger area were estimated based on a possibly skewed sample.

In addition, there can be difficulties in achieving a data set that is sufficiently disaggregated to estimate the impact of policies on particular transport sectors, for example the freight sector. Cost is often the key factor limiting the size of a data set, while commercial confidentiality may also be a consideration.

Much transport modelling relies on the estimation of elasticities to predict changes in behaviour as a result of changes in factors such as cost and time travelled. These are estimated using either cross-section or time-series data, and elasticities can vary according to whether the behavioural change being examined is a short-run or long-run response. For example, in the short-term, an increase in the price of fuel may lead to people making fewer car journeys. Over a longer term, they may choose to live closer to work or to locate near public transport, thereby further reducing the demand for fuel. However, they may also purchase a more fuel-efficient vehicle which, by offsetting some of the increase in costs from the higher fuel price, will work to increase the number of kilometres travelled (this is known as a second round or rebound effect and is discussed below).

Other data constraints include the use of emission factors. These are often calculated under specific test cycles that do not necessarily represent actual driving conditions. Particular problems arise when emission factors are applied to vehicles travelling at low speeds and in congestion.

Limitation in quantifying the degree of enforcement and the scale of policy adoption

For some measures, it is difficult to accurately predict their likely adoption. The outcome of measures such as increasing drivers' awareness of how to drive in a fuel-efficient manner (*e.g.* maintaining their tyres at the correct pressure, and braking and accelerating smoothly), or off-peak commuting are influenced by the voluntary actions of people. It is generally very difficult to predict/estimate the total number of people who changed their behaviour in response to the measure.

Unpredictability of future technological advancement

New technologies involving hybrid and fuel cell cars have the potential to dramatically reduce the amount of CO_2 emitted per distance travelled. However, there is significant uncertainty, particularly with fuel cells, surrounding the likely cost-effectiveness and therefore their rate of penetration into the vehicle fleet which will in turn depend on factors such as consumer acceptability.

Cross-cutting issues

There are a number of ways to estimate the costs and benefits of potential CO_2 reduction measures. The purpose of this section is to present some of the issues that need to be considered regardless of the modelling technique used. These issues include: isolating and estimating the benefits and costs of the CO_2 reduction strategy and estimating the impact of combinations of measures.

Estimating benefits

In order to estimate the impact of a GHG reduction strategy, a business-as-usual reference case on the road transport sector is required, including estimates and forecasts of traffic, fuel use and emissions in the absence of any new policies. From this baseline, reductions in emissions from a GHG reduction strategy can be estimated and projected for the target year.

For some GHG reduction strategies, there may be a second-round or rebound effect. This means that, over the longer term, once users adapt to the reduction strategy, emission reductions will be smaller than expected. For example, a measure that leads to improved vehicle fuel-efficiency may result in initial emission reductions. However, because increased fuel efficiency reduces the cost per kilometre travelled, the demand for travel often rises. Thus, some of the emission savings are negated by increased distance travelled. How best to model second-round or rebound effects is a key issue in modelling GHG reduction strategies. Elasticities based on empirical research are often used to estimate the level of consumer response to changes in price (and other factors such as journey time).

Other issues relate to estimating wider benefits/costs of greenhouse gas reduction strategies. These are considered in more detail below.

Monetary values of environmental emissions reductions continue to be of sufficient uncertainty that they have not been routinely adopted in standard cost-benefit models. However, techniques are improving and estimates are increasingly being used. Monetary values of travel time or transport-accident risk reductions have been adopted to a greater extent.

Estimating costs

In order to compare estimates of cost-effectiveness among GHG reduction strategies, the costs must be estimated on a consistent basis. This requires the use of commonly accepted concepts and measurements. In particular, consideration should be given to: common currency units; incremental and comprehensive costs; taxes, fees and tolls, and transport activity restrictions:

- *Common currency units*: when comparing the costs of various GHG reduction strategies, it is important to use common currency units. For example, all strategies could be evaluated using constant USD at prices in the year the analysis was undertaken. Future amounts should be represented by their equivalent "present" values using a uniform discount rate.
- *Incremental and comprehensive costs*: only costs arising from the GHG reduction strategies are relevant to estimating the cost of the strategy. However, any cost imposed by the strategy, including costs imposed on private sector operations and transport users, are relevant to estimating the total cost of the strategy.
- *New taxes/fees/tolls*: GHG reduction strategies may include financial costs to users that are imposed by government, such as fuel taxes, vehicle purchase taxes, vehicle licence fees, and road tolls. These financial costs are not included for the purposes of estimating cost-effectiveness ratios since they simply represent a transfer payment between taxpayers (but are taken into account in demand assessments).
- *Transport activity restrictions*: a number of GHG reduction strategies will achieve their effects by imposing some sort of activity restriction through government regulation. For example, activity restrictions could include road speed limits, restriction of hours of operations in cities, and minimum occupancy rules. For these GHG reduction strategies, the immediate monetary costs attributable to the government regulation might be quite small, perhaps simply representing the costs of enforcement. However, attempts could also be made to identify the costs involved in the changes in activities induced by the regulation. There may be additional financial costs to businesses as they adapt their operations to the regulations.

There may also be extensive costs to individuals. These would arise as increases in travel times, reductions in trips or replacement by pooled trips or shorter trips. These costs to individuals might not have any obvious monetary value, but may be unwelcome effects of the measures. It may be possible to assign monetary values to these costs and, they could, as a result, prove to be the major components of costs for some GHG reduction strategies.

As a start to monetising some of these welfare costs, some models use a generalised cost of travel, where changes in travel times change the cost of travel. Once a cost of time has been calculated, the task of monetising increases in journey times can be relatively simple.

Cost-effectiveness

Cost-effectiveness analysis is particularly useful when comparing different schemes where not all of the properties being considered have an explicit monetary value, in this case reduced CO_2 emissions. It can also be important when considering an efficient mix of measures to achieve pollution-reduction targets.

The cost-effectiveness of a measure can vary greatly depending on where it is applied and how it is apportioned. Excessive apportionment can lead to undesired side-effects and consequently to reduced efficiency. Measures are divided into two broad categories:

- Technical measures which can lead directly to reductions in emissions. The resulting costs will be relative to a specific reference technology. They are relatively simple to determine in the case of end-of-pipe technologies (*e.g.* filters), but less so in the case of technological improvements (*e.g.* attempts to reduce fuel consumption in engine technology).
- In the case of behaviour-oriented measures, the relationships are somewhat more complex. To determine the costs and effects, accurate information on traffic behaviour is needed.

In general, only those costs additionally incurred as a result of the measure need to be considered. The greatest problem arising on the cost side is the determination of the adjustment costs.

Some environmental protection measures have wide-ranging effects. For example, speed restrictions of 30 km/h in urban areas have a relatively broad spectrum of effects, including increased traffic safety. An assessment of the cost-effectiveness must take into account the potential synergies (or perhaps conflicts) of these measures.

Assessing combinations of measures

In estimating the combined effects of GHG reduction strategies, it is important to avoid "double-counting" emission reductions. This is sometimes referred to in modelling as the problem of additionality. Where different GHG reduction strategies target the same emissions (*e.g.* vehicle standards, reduced vehicle speeds, fuel taxes, driver behaviour modification), if the estimated effects are simply added, there will be double counting. The effects of combined measures can be more accurately approximated by expressing the independent effects of each of those strategies as proportional changes in emissions, then multiplying baseline emissions by the proportional reductions of each programme successively. Where the GHG reduction strategies target different road users, their effects will be additive.

The combinations and sequencing of GHG reduction strategies can also affect the cost-effectiveness ratios of the options. For strategies competing for the same traffic, options undertaken earlier will have larger absolute effects than those undertaken later, when emissions have already been reduced by other options.

Indicators and the evaluation of other impacts

In assessing the impacts of GHG strategies, it is important to focus on indicators from which real outcomes can be determined (OECD, 1999). For example, reducing traffic is not an end in itself; the key outcomes are often congestion, local air quality and CO_2 emissions. Accordingly, for a comprehensive evaluation of the impact of CO_2-reducing policies and measures, a wide range of criteria need to be taken into account, both to identify potential synergies with other initiatives and to avoid unintended effects that undercut other worthwhile goals. This section illustrates some of the potential synergies and negative impacts that need to be taken into account in developing and implementing a strategy or policy to reduce GHG emissions in the transportation sector.

Other benefits of GHG *reduction strategies*

GHG reduction strategies may provide benefits that go beyond GHG emission reductions. For example, they could reduce local air pollutants at relevant locations and times. Equally, just as a strategy may produce synergistic benefits, it may also create negative impacts on the environment or economy. While a shift to increased diesel fuel usage might show promise as a means of reducing CO_2 emissions, this strategy could also have negative environmental impacts by producing higher levels of particulate matter and NO_X emissions. The successful development of electric vehicles could achieve significant reductions in tailpipe emissions of CO_2, but assessments also need to take into account the emissions involved in producing the electricity required for battery charging and the challenge of proper environmental handling and disposal of used lead batteries, which poses a significant problem.

This holistic approach to the evaluation of potential strategies – examining the interrelationships among a range of environmental, economic, institutional, and social factors – is consistent with best practices for transportation policy development. Table 8 summarises seven criteria that are often used to evaluate potential strategies – drawn in part from work done by the US Department of Transportation and the Canadian Options Paper of the Transportation Climate Change Table. Because the specific priorities, needs and institutional structures of individual countries are unique, transportation decision makers naturally apply these criteria differently.

Table 8. **Evaluation framework for transportation strategies**

Criteria	Analytical considerations	
Greenhouse gas reduction benefits	Million tonnes of carbon equivalent reduction achieved	
Cost	• Monetary costs • Transfers	• Direct *vs.* indirect economic costs
Feasibility/uncertainty	• Political • Legal • Technological • Behavioural	• Ease of implementation/institutional • Scope • Enforceability
Synergistic benefits	• Other environmental benefits (*e.g.* pollutant reductions, decreased congestion)	• Economic growth • Energy security • Access/mobility
Negative impacts	• Negative environmental effects	• Macro- and microeconomic shifts
Equity	Impacts across: • Population groups	• Regions • Generations
Temporal scope	• Time to develop/implement	• Time to achieve results

The table includes a wide range of criteria in addition to the identification of potential synergies and negative effects. The *equity* impacts of a strategy may also affect its viability. An otherwise promising strategy may create economic hardship for particular population groups, place undue burdens on certain geographic areas, or produce long-term negative effects that would be left to future generations to resolve. The *temporal scope* of strategies should also be examined. Since some of the most promising strategies to reduce greenhouse gases will not be ready for implementation in the near future, decision makers may need to consider the relative advantages of strategies that can be implemented to begin reductions in the near-term.

The application of the criteria listed in Table 8 is illustrated by highlighting their potential relevance to two of the four major categories of measures to reduce GHGs from road transport, as presented in Chapter 3. These categories are: *i*) improving vehicle fuel consumption; and *ii*) reducing transport demand.

Improving vehicle fuel consumption

Reducing CO_2 emissions by improving fuel efficiency is an important strategy undertaken by most OECD countries. Many countries (including Australia, Canada, the Czech Republic, Japan, Korea and the United States) and the European Union have set or are currently negotiating fuel consumption standards/targets to trigger the development of vehicles with improved performance. This strategy can also support several *synergistic benefits*, which may include reduction of criteria pollutants, greater energy security, and the promotion of technology advancements. However, the *temporal scope* of specific strategies may be a factor in how rapidly significant greenhouse gas reductions can be achieved.

The issue of the *costs* of a strategy and *cost transfers* (*i.e.* who incurs that expense) is illustrated by the US experience in implementing its Corporate Average Fuel Efficiency Standards (CAFE). Historically, due to a relatively low elasticity in travel demand, US consumers have incurred the cost of fuel-inefficient vehicles by buying more fuel to support their travel demand. CAFE mandates higher fuel efficiency on an average basis for fleets produced by each manufacturer. It appears that manufacturers have subsidised the costs of development of the more fuel-efficient vehicles in their fleets. To the extent that these costs are not passed on to the consumer (whose fuel expenses are reduced through purchase of a more fuel-efficient vehicle), this represents a cost transfer from the consumer to the manufacturer.

Reducing transport demand

Several countries have introduced measures to control transport demand and alleviate road traffic congestion. A number of these are pricing measures, which set fees or charges as a means to better reflect the full cost of transportation activities. Road pricing, parking fees and fuel taxes are examples of these market mechanisms, since increasing the costs of transport reduces travel to some degree, thereby reducing CO_2 emissions. Other examples include mass-distance charges (*e.g.*, New Zealand), and carbon taxes (such as Norway's CO_2 tax). However, the effectiveness of pricing measures will be affected by the elasticity of travel demand. In general, consumers have demonstrated low demand elasticities for travel; prices may have to be set substantially higher, therefore, to achieve real reductions in travel. The potential *negative impacts* of these higher travel costs on the economy and public quality of life need to be evaluated. Furthermore, higher prices for travel may impose regressive cost burdens on lower-income groups, raising concerns about the *equity* of the strategy.

The potentially negative impacts of pricing measures may be addressed through the implementation of concurrent strategies designed to compensate for these effects. For example, measures such as ride-sharing, car-sharing, telecommuting and trip-reduction programmes may provide alternatives for consumers to meet their mobility needs, as could increased provision of transit services (as discussed in the following section). Equity concerns could be addressed through a programme of income-based rebates or tax credits to offset the economic burden to lower-income consumers. A full examination of such potential negative effects prior to the implementation of a new strategy or policy can help decision makers avoid unintended consequences on consumers or the economy in general.

Evaluation methods

Current experiences with modelling

This section provides an illustrative description of the different approaches to modelling and types of models used across OECD countries. It is important to note that this does not represent a comprehensive assessment of individual countries' modelling capacity; rather, the intention is to give a flavour of both the diversity and similarities of the different modelling approaches employed.

Forecasting models are generally described as being either "bottom-up" or "top-down". Bottom-up models are built up from micro-level data (for example, a fuel efficiency model built up from disaggregated information on the vehicle stock). Top-down models are based on equations capturing historical relationships between macroeconomic variables (for example, a top-down fuel use model would be based on macroeconomic equations estimating the demand for fuels used by road transport).

Australia

Australia's Bureau of Transport Economics has developed CARMOD, a model of the dynamics of the Australian car fleet (Bureau of Transport and Communications Economics, 1996*a*). CARMOD incorporates a number of policy simulators that can be used to examine policy options aimed at improving the performance of the car fleet in terms of fuel efficiency or emissions. The model is in a simple spreadsheet format to provide maximum transparency of the calculations and to permit users to easily change internal data and parameter values.

The main segment of the model framework is the estimation of fuel consumption derived from data on the number of vehicles, the number of kilometres travelled and the average fuel consumption. The number of cars per 1 000 population for Australia has been modelled as a logistic (or S-shaped) function which imposes an upper bound (or saturation level) on motor vehicle ownership. Once the total vehicle stock for a particular year has been determined, the number of new cars entering the fleet during that year is calculated. New vehicle sales are estimated as the increase in the total stock over the previous year plus the number of vehicles scrapped during the year. Scrappage functions are calculated from year-to-year differences of points on vintage survival curves. The model allows for deterioration in fuel efficiency with age and also for increases in fuel use as a result of congestion.

Once the model has estimated the total vehicle kilometres travelled for each vintage and associated fuel consumption, emissions of CO_2, methane (CH_4), nitrous oxide (N_2O), other oxides of nitrogen (NO_x), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs) are calculated using vintage-specific emission rates. To represent the total greenhouse effect from the emissions of several different gases, emissions are expressed in CO_2 equivalent emissions.

Australia also has a model of the Australian truck fleet and road freight task: TRUCKMOD. The model examines two possible policy measures to reduce greenhouse gas emissions from road freight vehicles: the accelerated adoption of more fuel efficient vehicle technology and the accelerated retirement of less fuel-efficient vehicles. Analysis using TRUCKMOD shows that accelerated vehicle technology uptake would result in a significant reduction in greenhouse gas emissions. Accelerated retirement of less fuel-efficient vehicles is a very expensive policy, with a very small reduction in emissions at very high cost. (Bureau of Transport and Communications Economics, 1996*b*).

Canada

Canada has an integrated modelling framework consisting of the InterFuel Substitution and Demand (IFSD) model, the Canadian Power Planning model for utility generation, and the Oil and Gas Supply model. The modelling structure also includes several detailed end-use models including one for the transportation sector.

The IFSD model consists of econometrically-estimated behavioural equations based on the historical relationships between sectoral energy intensities and a set of explanatory variables, which include demographic and economic factors. It projects annual energy demand by fuel type and by sector in each Canadian province under alternative scenarios of economic growth, energy prices and other assumptions. For the road sector, IFSD models gasoline and diesel fuel consumption separately for both passenger cars and trucks. Demand for alternative fuels – propane, natural gas, methanol, ethanol and electricity – is based on the economics of these fuels relative to gasoline and other non-financial factors such as fuel availability. For each type of vehicle and fuel used, demand is based on a projection of the stock of vehicles, the average fuel efficiency and the average distance travelled per vehicle.

The following relationships are assumed in the model:

- The stock of vehicles on the road is obtained by applying survival rates to previous sales of new vehicles.

- New car/truck sales are based on the cost of financing, real gasoline price and a macroeconomic variable (real personal disposable income for passenger cars and total GDP for trucks).
- Average distance travelled is a function of the price of fuel per kilometre and a macroeconomic variable (same as above).
- New car/truck fuel efficiency is either exogeneously determined or estimated on the basis of past and current gasoline prices.

Canada also uses the Transportation Energy Demand Model (TEDM). This is a bottom-up model designed to assess energy-efficiency trends in Canada's transportation sector. TEDM is disaggregated at the provincial level and includes nine categories of vehicles and five fuel types.

Car and truck stock data used in TEDM are based on the actual fleet of vehicles registered in Canada, while data on new sales and the stock of buses and motorcycles are taken from Statistics Canada publications. The car and light truck road fuel economy used in the model are based on laboratory-tested fuel economy, adjusted for road conditions. Using the vehicle stock and use characteristics, average distance travelled by vehicle age and vehicle type, as well as the vehicle fuel economy by fuel type, the model estimates the annual fuel use for each province and vehicle category represented in the model. This is done by calibrating estimated provincial road energy demand to the transportation sector's provincial energy demand data.

Norway

Norway has developed a suite of models to analyse and forecast CO_2 emissions. RETRO is a regional, bottom-up, real network transportation model for the greater Oslo area. It consists of a traditional transport model with route assignment, mode choice and destination choice and trip frequency. The model responds to several transport measures, including toll charges, parking charges, annual car tax, fuel tax and congestion charges, public transport frequency and infrastructure investments. Changes in CO_2 emissions can be calculated on the basis of RETRO results for total vehicle kilometres travelled and the average speed between zones in the modelled area. The model output can be used with cost-benefit analysis for evaluation of the economic efficiency of the measures (Vold, 1999).

Norway also uses GODMOD, a top-down general equilibrium model, to estimate the impacts of CO_2 reduction policies. In particular, GODMOD has been used to investigate various aspects of "eco-friendly" transport technologies in connection with CO_2 emissions from the transport sector. An important question was whether the use of eco-friendly transport technology could reduce the cost of implementing a Norwegian climate policy in connection with the Kyoto Protocol, and also to determine technologies, which in the short and long term are best suited to reducing CO_2 emissions in the transport sector. Calculated effects on emissions can be estimated in scenarios with and without emission trading and with and without technology changes.

According to GODMOD, the goal of complying with an overall CO_2 emission target of 1% above the 1990 level (the Kyoto Protocol) is equivalent to reducing emissions by 19% compared to projected emissions in 2010. This will reduce GDP by 0.5% in 2010 and 0.7% in 2020 in relation to the business-as-usual case (which assumes no new gas-fired power plants). GDP losses increase to 4.1% if a 55% reduction in emissions in 2010 is sought, and correspondingly 5.9% to maintain the same emissions level in 2020.

Switzerland

The Swiss approach to modelling CO_2 policies and measures in the transport sector emphasises the importance of traditional cost-benefit analysis as well as comparisons of the cost effectiveness of measures.

The application of cost-benefit analysis in Switzerland is directed toward assessing the impact of measures. It is aimed at a direct, financially quantifiable comparison of the costs and benefits of measures aimed at reducing CO_2 emissions. The model serves as a working tool that makes it possible to assess measures already introduced (*ex post*) and also acts as an aid to decision making in planning measures (*ex ante*). It is intended to facilitate decisions regarding practical implementation and increase the transparency and feasibility of political decisions.

The costs are calculated on the basis of cost data in the project development or planning phase. The benefits are transformed into monetary values using estimates of "willingness to pay". By comparing the costs and benefits, it is also possible to state the efficiency of measures.

United Kingdom

The United Kingdom has two main models for estimating the behavioural impacts of specific measures and/or package of measures, which together form the climate change modelling framework. These are the Vehicle Market Model (VMM) and the National Road Traffic Forecast (NRTF). Both use a bottom-up approach.

The United Kingdom also has an energy-demand model, which is used to model CO_2 emissions from a range of sectors, including transport. In contrast to the VMM and the NRTF, the energy-demand model is based on a top-down approach.

- Vehicle Market Model

The Vehicle Market Model (VMM) is a national, fuel-consumption model similar in structure to Australia's CARMOD. It enables the user to investigate the effects of different policy levers, such as changes in fuel taxes, on the fuel consumed nationally by road vehicles. It estimates the fuel used for four classes of vehicles: cars, light vans and other goods vehicles, heavy goods vehicles (HGVs) and buses/public service vehicles. Each of these categories is disaggregated into several vehicle types. The forecasting period is 1996-2031 (Kirby *et al.*, 1998).

The VMM also contains a fuel consumption forecasting sub-model. This technology sub-model estimates the fuel consumption of new cars in the future by using a scenario of likely technological changes.

The adoption of various fuel-saving technologies in the car fleet is dependent upon the cost of fuel and hence the point at which adoption of the technologies becomes cost-effective. That is, once fuel prices rise to a certain level, the fuel savings from certain technologies will outweigh the cost of the technology. Once the payback period falls to three years or less, it is assumed that manufacturers will incorporate the technology in their new cars. The fuel-consumption forecasting model also takes into account the likely minimum time between production of a specific technology and its full penetration in the new car market. Thus, savings are spread over a number of years. It disaggregates by fuel type; hence, the relative fuel efficiency of petrol and diesel cars can change over time.

- National Transport Model

The UK Government is developing a new National Transport Model (NTM). It will provide medium- and long-term forecasts of the use of the various modes of transport by both passengers and freight. The NTM will also provide forecasts of CO_2, PM_{10} and NO_x emissions from road and rail transport; the congestion associated with road transport; and road accidents.

The NTM will model how these forecasts vary with assumptions for future years on:

- National income, population, employment and car ownership.
- The cost of using each mode [in particular, fuel costs for road transport, taking account of the price of fuel (crude oil price, refining, distribution and taxation) and vehicle efficiency].
- Policies such as national roads investment, national rail investment and policies affecting rail fares.
- Local transport policies, including capital investment in bus and light rail, revenue support for bus and rail, and measures affecting the cost of car use (such as restrictions on use of local roads, parking charges, road user charges and workplace parking levies).

Traffic forecasts take into account how traffic responds to congestion by changing routes, changing time of travel and switching to nearer destinations or other modes.

Forecasts of emissions from road traffic in a future year depend on:

- Quantity of traffic.
- Speed of traffic.
- Mix of the vehicle stock in terms of fuel efficiency and type of fuel used.

- Energy Demand Model

Projections from the energy demand model are based on an analysis of historical trends in energy use and its relationship to factors such as economic growth and fuel prices. They also reflect the impact of existing government policies on energy and the environment. The projections provide a view of possible future levels and composition of energy demand based on a set of different scenarios of growth in the economy and of world fossil-fuel prices. Six core scenarios are considered.

The energy demand model is based on approximately 100 econometric equations. The forecasts can be disaggregated into different sectors, including transport. The transport sector consists of a number of econometric equations that attempt to explain past energy demand as a function of other variables such as prices and income or output levels. These equations implicitly incorporate historic trends in vehicle fuel efficiency. Where reliable information exists, stock data has been incorporated into the equations (for example, the stock of cars) (UK Department of Trade and Industry, 2000).

United States

There is a multitude of topic-specific greenhouse gas models that can assess specific aspects of GHG control strategies in the transport sector with high levels of sophistication (FHWA, 1999). Their integration is not complete, but analysis of integrated strategies is possible with user intervention.

- Vehicles and Fuel Models

These models were developed to assess broad policy options related to vehicle fuel economy, national consumption of fuels, and national environmental issues. There are four types of models: conventional fuel vehicles; alternative fuel vehicles; vehicle sales and sales mix and vehicle availability.

The Technology/Cost Segment Model applies primarily to light-duty vehicles. Technology is described in five data inputs: the impact on fuel economy, the impact on cost, the interactions with other technology, the effects on other vehicle attributes of interest to the consumer and the date of first availability. This information is used to predict fuel economy changes over time and the impact on vehicle price, using a model of auto industry behaviour (based on product life-cycle and tooling constraints), while holding vehicle attributes of size and performance constant.

A number of models are available to project the attributes of alternative fuel vehicles. Generally, these models assume that alternative fuel vehicles are derived from conventional vehicles, and attributed changes have generally been specified in percentage terms. Alternative fuel vehicle analysis is not conducted at "constant attributes", but explicitly specifies attribute losses for performance, range, interior room and refuelling time. These forecasts generally suffer from assumptions about technology improvement and price decreases in the future.

Vehicle sales, sales mix and attribute demand functions are largely estimated by input-output models based on regressions of historical data. This area is potentially the least advanced of the greenhouse gas modelling sequence. Total vehicle sales are available from Data Resources, Inc. (DRI) and Chase Econometrics that maintain large input-output models representing the entire US economy. Sales mix by vehicle type and size have proven very difficult to forecast due to changing consumer tastes in the light-vehicle market.

Vehicle availability is typically modelled as part of an urban area's or state's travel forecasting process. Vehicle availability is most commonly forecasted as a function of socio-economic variables, including household income, size, and location.

• Fuel Supply and Infrastructure Models

The Alternative Fuel Trade Model (AFTM) compares long-run static pictures of the energy economy under alternative scenarios or policies, without explicit consideration of the intermediate adjustment process. The approach focuses on: prospects for fuel substitution; long-run effects of alternative motor fuel use on oil and gas demand, refining, imports and fuel prices; and, ramifications of possible monopolistic responses by oil and gas exporters.

Alternative fuel vehicle choice models are either based on stated preferences from surveys of consumers or on a "welfare maximising" model of consumer choices.

The Transitional Alternative Fuels Vehicle (TAFV) Model simulates the use and cost of alternative fuels and alternative fuel vehicles over the time frame 1996-10. The model attempts to characterise the evolution in the use of AFVs in the United States as new technologies – that were until now expensive and produced in low volumes – are offered at lower costs and developed on a wider scale. The model also focuses on how the transition might happen and what its associated costs would be.

• Transportation

These models were developed primarily to assess the impacts of transportation investments (*e.g.* highway and transit system construction) and policies (*e.g.* high-occupancy vehicles).

• National Transportation Performance Models

The Transportation Research Board (TRB) uses a model in its "sustainable future" analysis to forecast CO_2 emissions at the national level. It is based on national vehicle miles travelled (VMT) and fuel efficiency forecasts. The explanatory variables in the basic model, including gross domestic product per capita, fuel price per gallon, fuel price per mile driven, new vehicle price index, labour force participation rate, road miles per licensed driver and vehicles per capita, are estimated through a series of log-log regression equations. The model also applies a CO_2 emissions rate to the VMT estimates to derive total CO_2 emissions. The effects of GHG strategies are thus estimated through changes in VMT, fuel efficiency, and the CO_2 emissions rate of vehicles. For forecasting a baseline estimate of CO_2 emissions from 2000 to 2040, VMT is assumed to increase at 1.5% per year. The model is then applied to four GHG strategies: reduction in motor vehicle demand, increase in motor vehicle fuel economy, higher motor fuel prices and development of low GHG emitting vehicles.

International Energy Agency (IEA)

• World Energy Model

The World Energy Model (WEM), which serves as the basis for the IEA's *Outlook*, is a mathematical model made up of four main sub-models: final demand, power generation and other transformation, fossil fuel supply and emission trading. The main exogenous assumptions are GDP, population, international fossil fuel prices and technological developments. The level of electricity consumption and electricity prices link the final energy demand and power generation modules. Primary demand for fossil fuels serves as input for the supply modules. Energy balances are calculated using the outputs of the three modules for each region. CO_2 emissions can then be derived using implied carbon factors. The emission trading module uses marginal abatement cost curves, obtained by an iterative process of running the WEM with different carbon values.

The IEA developed recently a Transportation Module. It is a bottom-up model that was developed as a complement to the WEM using a disaggregated framework to generate transport sector specific results. For every region, activity levels for each mode of transport are a function of population, GDP and price. The elasticity of transport activity to the fuel cost per km is applied to all modes except passenger and freight rail and inland waterways. In the case of passenger vehicles, this elasticity is also used to determine the rebound effect of increased transport demand resulting from improved fuel intensity. Additional assumption to reflect passenger vehicle ownership saturation are also made. Modal energy intensity is projected taking into account changes in energy efficiency and fuel prices. For cars and light trucks, stock turnover is explicitly modelled in order to allow for the effects of fuel efficiency regulation of new cars on fleet energy intensity. Fuel efficiency regulation for new cars and light trucks as well as (additional) fuel taxation can be directly modelled (IEA, 2001).

European Commission

- Auto Oil II

The Auto-Oil II programme was established by the European Commission in 1993 to identify the most cost-effective means of improving air quality throughout Europe, through improvements to both vehicle technology and fuel specification. The programme consisted of seven working groups; one on cost-effectiveness has developed a transport policy simulation tool, the TREMOVE model (European Commission, 1999). This model is designed to develop and support cost-effectiveness analysis by producing costs and emission effects for a wide range of both technical and non-technical measures aimed at reducing emissions from road transport. Although the main scope of the model is to address air quality, one of its outputs is the quantity of CO_2 emitted. It is therefore relevant to this study.

- TREMOVE

TREMOVE is a behavioural rather than a transport-forecasting model. It simulates changes in consumer behaviour due to changes in economic conditions arising from the implementation of new measures. For example, a change in fuel duties has an impact on generalised road transport costs. Consumers respond through their choice of transport mode, vehicle type and transport demand. These choices affect the emissions of the vehicle fleet.

There are three main facets to the model: the cost and traffic module, vehicle stock module and an emissions module.

- First, the transport cost and traffic module calculates the effect that a measure has on the demand for different modes and vehicle categories. Modal choice is determined by the relative generalised cost of each mode, income levels and given consumer preferences. The generalised cost of a mode includes the cost associated with the time spent travelling. The model includes road transport (cars, freight, buses, taxis and motorcycles and bicycles), rail – metro and train (passenger and freight) and in-land waterways.
- Second, the stock module converts changes in transport demand, from the above module, into stock figures for each type of vehicle.
- Third, the emissions module calculates the level of emissions arising from the number of kilometres driven by each type of vehicle.

In summary, the model estimates the impacts of policy measures on consumer choice and hence on road transport emissions. For example, if fuel duties rise or road pricing is introduced, consumers would be expected to adjust their behaviour by reducing their demand for transport *per se* and/or switching to other modes. The total kilometrage for each mode is then determined, from which the impact on vehicle stock and average usage of vehicles is calculated. The model then calculates the emissions from this total demand for transport and modal split.

TREMOVE is a cost-effectiveness model; it not only produces emissions changes arising from implementing a policy, but also calculates cost differentials between different transport measures. The cost is expressed as the cost to society, comprising a number of factors: costs to transport users such as car owners and freight transport operators which would include time costs arising from changes in congestion levels; and costs, positive or negative, to government. It also calculates the side-effects of a measure in terms of accident and noise costs. The model allows measures to be compared and selected in terms of their cost-effectiveness.

What is missing? Improving current modelling approaches

Quality of data

Although many of the models currently employed are highly disaggregated, there are a number of common data issues, many of which are centred on the emission factors used.

Most disaggregated models that employ a bottom-up approach use official fuel efficiency figures for vehicles. These are then projected into the future, with the projections dependant upon expectations of the availability of future fuel saving technologies. However, the official fuel consumption figures (litres per 100 km) are calculated for vehicles without options such as air conditioning and headlights being switched on. Thus, the official figures can understate actual fuel consumption by up to 25%. The obvious implication of this is that total fuel consumption forecasts are being significantly understated and, therefore, so too are carbon dioxide emissions.

To overcome this problem, one of two courses of action is needed: either new fuel consumption figures are produced; or a representative scaling factor is employed during modelling. The former would require a more realistic test cycle being conducted for each vehicle with options such as air conditioning being switched on for a certain proportion of the test, thereby mimicking real-life conditions. The latter would simply require the calculation of a factor that would scale the forecasted total fuel consumption figure to the actual reported fuel sales figure. For example, if forecast fuel consumption was 1 million litres and fuel sales totalled 1.2 million litres, then the scaler would be 1.2. Further, the scaler is likely to change over time, reflecting changes to the proportion of the fleet that is fitted with options such as air conditioning.

Some models estimate CO_2 emissions directly from the total number of vehicle-kilometres travelled and standard emission factors per kilometre. However, many of the models allow for differences in CO_2 emissions according to the speed travelled; for example, low speeds are more fuel-intensive than speeds of around 60 km/h. Therefore, average speed dependent emission factors are applied. However, these factors become inaccurate when applied to congested roads. For example, a car on a motorway may travel at an average speed of 50 km/h; however, if there is congestion, the actual speed may range from 10 km/h to more than 80 km/h. At both of these extremes, CO_2 emissions would be higher than at 50 km/h; therefore, real CO_2 emissions would be underestimated. Australia makes an adjustment to CARMOD to allow for increased fuel use as a result of congestion.

Modelling approach

Life-cycle assessment

It is important to consider policies and measures not only in terms of their contributions to reducing GHG emissions in the road transport sector, but also in terms of their effects on GHG emissions in other sectors over the full life cycle of the measure. For example, an assessment of measures that promote the introduction of alternative-powered vehicles from the perspective of their life cycles must address the following:

GHG *emissions in building and maintaining vehicles*

GHG emissions in building and maintaining vehicles largely results from producing raw materials, processing the vehicle body, and repairing the vehicle. When the bodies of conventional vehicles and alternative-powered vehicles use the same materials, CO_2 emissions will be about the same for both, but many alternative-powered vehicle bodies use more aluminium to reduce the chassis weight. Because the amount of energy consumed to manufacture aluminium is higher than the amount consumed to manufacture steel, GHG emissions will increase.

GHG *emissions from operation*

GHG emissions produced from operating a vehicle are calculated by the amount of energy the vehicle consumes during the vehicle's life cycle. The life-cycle assessment includes the calculation of the emissions produced in manufacturing energy (mining, shipping, purification, and power generation).

GHG emissions produced in manufacturing energy differ by country, even if they have the same fuel consumption, due to conditions such as whether or not the country is an oil producer, and its form(s) of power generation.

GHG *emissions involved in vehicle disposal*

GHG emissions involved in vehicle disposal are the same when alternative-powered vehicles are made of the same materials as conventional vehicles. Because hydrofluorocarbons (HFC), used as a coolant for air conditioning systems, have a strong effect on global warming, there will be significant differences in the emissions involved in disposal depending on whether the coolant is collected or discarded.

Trade-offs between fuel efficiency and life cycle of CO_2

Some materials used to reduce the weight of vehicles to improve their fuel efficiency may require more energy for vehicle disposal or may be less environmentally-friendly.

Examples of measures requiring life-cycle assessment:

- *Vehicle fleet renewal programme* – this could be a programme offering grants and special tax measures when upgrading from an older car with poor fuel efficiency to a new model that incorporates the latest technologies and offers high fuel efficiency. Whilst effective from the perspective of reducing CO_2 emissions produced from operating the vehicle, the CO_2 emissions from producing and discarding vehicles will increase because the programme will shorten the life cycle of older vehicles. A comprehensive evaluation of the programme must be performed that takes into consideration the CO_2 emissions resulting from the production and disposal of vehicles.
- *Programme promoting the use of alternative-powered vehicles* – the life-cycle assessment of alternative-powered vehicles must take into consideration the CO_2 emitted in transporting and manufacturing fuel or generating electricity. The problem of battery disposal must also be considered in assessments of electric-powered and hybrid vehicles. Because alternative-powered vehicles are only just beginning to enter circulation, there are many aspects of CO_2 emissions resulting from disposal and other processes that remain unclear.
- *Installation of new public transport infrastructure* – when installing new means of public transport, such as railway systems, it is important to consider the CO_2 emissions resulting from the facility installation and its maintenance and management.

Lack of *ex post* evaluation

This project has identified a wide range of modelling capacity within OECD countries. However, this capacity is primarily focused on *ex ante* modelling of policies and measures. There is little evidence of such enthusiasm for *ex post* evaluation. This is partly a result of both the difficulty of isolating the impact of a particular policy when it may be part of a wide ranging package and the cost of evaluation, particularly when a policy entails changes in behaviour.

Box 1 compares Japanese and Canadian evaluation methodologies for their respective policies to increase the fuel efficiency of new passenger cars. It highlights the differences between the types of methodologies employed and also the care that must be taken with interpretation. A key issue when comparing evaluation methodologies is establishing how consistently the modelling and evaluation are applied across countries – there are likely to be significant differences in baselines, assumptions and interpretation.

Box 1. **Comparison of the evaluation methodologies used in Canada and Japan**

Both Canada and Japan plan to reduce fuel consumption by establishing standards for the fuel consumption of passenger cars and light trucks. In Canada, fuel efficiency targets for new cars have been set since 1980 by the Company Average Fuel Consumption (CAFC) targets established by the Motor Vehicle Fuel Efficiency Initiative. In Japan, fuel efficiency standards for vehicles are established by the Law concerning the Rational Use of Energy. Following revisions to the Law in 1999, passenger gasoline vehicles are set to improve their fuel efficiency by around 23% between 1995 and 2010. The target for diesel passenger cars is to improve efficiency by 15% between 1995 and 2005. If the efficiency improvements are not made, then the motor manufacturers can be fined.

Effects of fuel efficiency improvements to automobiles

The evaluations of fuel efficiency standards by Japan and Canada have highlighted a large difference between estimates of CO_2 emissions savings. Their estimates of the resulting reductions in CO_2 emissions are as follows:

Canada: 44 Mt CO_2/year (total CO_2 emissions from road transport amounted to 107 million tonnes in 1996).

Japan: 1.2 Mt-CO_2/year (total CO_2 emissions from road transport amounted to 217 million tonnes in 1996).

The significant gap between Canada and Japan with respect to the amount of CO_2 emissions reduced from their fuel consumption reduction measures may have partly been a result of the difference in the types of vehicles and the time period selected for evaluation.

While Canada conducted its evaluation over a 17-year period from 1978 to 1995, Japan's evaluation was for seven years from 1990 to 1997. The assessment period for Canada was thus comparatively longer than that for Japan. During those additional years, the efficiency of automobiles had improved. As a result, the estimated CO_2 reduction in Canada was significantly greater than that in Japan.

The example illustrated in Box 1 shows that when conducting a quantitative analysis of the CO_2 emissions reduction effects of measures implemented by different countries, it is important to be aware of the methods used to calculate those reductions. Differences in the set-up conditions of the evaluation methods may result in different evaluation results even when comparing similar measures. Because it is impossible to determine the quality of policies merely by conducting a simple comparison of values produced by calculating the effects of those policies, transparency in policy effect calculation methods is essential.

Other issues

- Double dividend

Most models[1] currently take no account of revenue recycling, the so-called "double dividend" effect. This effect occurs when a revenue-neutral environmental tax gives rise to both environmental benefits and reductions in the existing distortionary tax system.

Cost-effectiveness analysis and cost-benefit analysis should take into account both the direct and indirect (or downstream) effects resulting from a policy initiative, including employment impacts.

Terms of trade

Similarly, changes in the terms of trade that might arise from changes in energy prices if the Kyoto Protocol is delivered are also generally absent from models.[2] Such an effect will occur if, as a result of lower energy demand, energy prices fall. Thus, if a country imports or exports energy, then its terms of trade will also change. For example, if there is a shift to alternative forms of energy, a major oil exporting country such as Saudi Arabia will suffer from a negative terms of trade effect and, therefore, its balance of trade will suffer; whereas an importing country will enjoy an improvement in its terms of trade.

Conclusions

- There is a need to improve information to achieve more reliable forecasts – particularly in terms of emission factors and measures of elasticities.
- Forecasting and *ex ante* evaluation methods may be rigorous, but it is not always possible to assess the consistency of their application.
- There is a lack of *ex post* evaluation of national policies – while often difficult to conduct, this is an important part of the forecasting and evaluation process that is lacking in many cases.
- There needs to be recognition of limitations related to exogenous changes, *i.e.* when dealing with matters such as the impact of future technology and changing consumer tastes.

NOTES

1. The Norwegian CICERO analysis in working paper 1998:9 is one exception.
2. The CICERO Working Paper 1998:9 again is the same exception.

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Chapter 5

FUTURE TRENDS IN CO_2 EMISSIONS AND TECHNOLOGICAL IMPROVEMENTS

CO_2 emissions reduction policies

Future global CO_2 emissions need to be reduced in line with the decisions taken at the Kyoto Conference. The 1997 UN Kyoto Protocol established greenhouse gas emissions reduction goals for parties included in Annex I to the Convention. All economic sectors (*e.g.* industry, households and transport) are involved in national actions to meet the different greenhouse gas reduction goals nominated by the Annex I (developed) countries.

In many countries, agreements have been signed in key sectors of industry that specify actions to be taken to contribute to the Kyoto goals. Examples include:

- In the industrial sector, agreements to reduce the energy cost and CO_2 emissions from industrial production. In France, for example, steel manufacturers and the French Government signed a protocol in 1996 to reduce the overall steel industry emissions of CO_2 by at least 10% between 1990 and 2000.
- In the road transport sector, agreements to reduce fuel emissions of new motor vehicles. For example, the European car-makers (ACEA) concluded a voluntary agreement with the European Commission in 1998 to reduce CO_2 emissions of new passenger cars to 140 g/km in 2008, and undertook to produce very low emission models (120 g/km and lower).

Such measures could be expected to contribute to reducing CO_2 emissions.

However, changes in recent levels and short-term projections for CO_2 emissions are not moving in this direction – CO_2 levels are currently increasing and are expected to continue to do so, at least in the short term. There are several reasons for this increase. All are linked to current high levels of economic growth in industrialised countries, especially in Western Europe and in the United States, where economic growth has been strong since 1994. Further, there are wide differences in level of fuel taxes and vehicle taxes across countries, which in part may contribute to the sharp disparity in vehicle ownership rates across OECD Member countries, as well as the types of vehicles purchased in those countries. Unless tax regimes favouring high levels of vehicle ownership, coupled with strong demand for travel using high emission vehicles, are reversed, then the above expectation will likely continue into the longer term.

Factors influencing road emissions by passenger cars

Total emissions of CO_2 from passenger cars depend on several principal factors:

- Unit fuel consumption (in litres/100 km or in miles/gallon).
- Average annual distance travelled.
- Number of vehicles in use.

Unit fuel consumption (or unit CO_2 *emissions)*

Passenger cars sold in 1999 in Europe have an average emissions rating of close to 175 grams of CO_2 per kilometre travelled. This average is derived from certain variables that need to be discussed:

- The average emissions rating is obtained by measurements conducted in accordance with "official cycle" tests, without using accessories which consume energy, such as headlights, air conditioning, etc.; the cycle itself is not representative of the real uses of vehicles, particularly in high-load driving periods.
- Different models have varying levels of emissions based on their engine specifications, even with the same vehicle body type. In Peugeot's 206 model range , the "official" estimates of CO_2 emissions vary from 136 to 187 grams per km; in the 406 model range, the CO_2 value varies from 150 grams to 260 grams. In the Golf range from Volkswagen, the CO_2 value varies from 132 to 259 grams per km.

Therefore, while a passenger car model may be supplied to the international market with, for instance, an emissions level of 119 grams per km of CO_2 (measured on an official test cycle), its real emissions are closer to 150-160 grams under actual driving conditions. Factors such as varying driving speeds in accordance with traffic flow and air conditioning systems must also be considered.

Technological innovations to reduce CO_2 *emissions*

Two important motor vehicle programmes have been launched, one in Europe and the other in the United States, with similar objectives relating to reducing fuel consumption and CO_2 emissions.

In Europe, the initiative is being undertaken by the ACEA, with significant grants from the European Commission and from different national governments. In the United States, the initiative is being undertaken by the three major vehicle manufacturers, with significant grants from the US Government (PNGV – Partnership for a New Generation of Vehicles).

European vehicle manufacturers are planning to produce two ranges of vehicles:

- A small-sized model, 650 kg, power limited to 25-28 kW, and with CO_2 emissions of 70-80 g on an official cycle (90 to 100 g in real use).
- A medium-sized model, 900 kg, power limited to 40-45 kW, and with official cycle CO_2 emissions of 120-130 g (140 to 150 g in real use).

American vehicle manufacturers' plans are similar; the objective is to produce a production prototype of a very low-fuel consumption passenger car by 2004.

All the European and American vehicle manufacturers involved have decided to use "classical" engines, with gasoline and diesel fuels, but with new technologies (direct fuel injection with downsized engines, turbo charging, camless engines, minor hybrid systems, etc.).

Given the model characteristics and the low power engines of low-fuel vehicles, it will be very difficult for manufacturers to maintain all the comfort-related accessories that are so common in current passenger vehicles. The new vehicles are expected to have adequate performance for driving in town, on major roads and on highways, but lower performance than vehicles currently available, especially in relation to acceleration, maximum speed and stability in curves.

It is uncertain whether drivers will chose to buy new-generation passenger cars, with reduced performance and less comfort, in favour of current generation vehicles with superior performance and features.

Recent trends have in fact been moving in the opposite direction. As disposable incomes increase, consumers increasingly choose heavier and more powerful vehicles which provide increasing levels of comfort and equipment while maintaining or increasing road performance. As an indication of these trends, the recent growth in the average power of passenger cars in four European countries is illustrated in Table 9.

Table 9. **Average power of new passenger cars in four European countries**

	1996	1998	1999	2000
Germany	71 kW	76 kW	78 kW	81 kW
France	57 kW	63 kW	65 kW	67 kW
Italy	61 kW	60 kW	62 kW	63 kW
United-Kingdom	70 kW	75 kW	76 kW	76 kW

Source: CCFA, July 2001.

Average annual distance travelled and number of vehicles in use

The average annual distance travelled per vehicle and the number of vehicles in use are useful parameters in assessing CO_2 emissions from transport. Details of the evolution of these measures in France are set out in Table 10.

Table 10. **France: number of cars and average annual distance travelled**

	Average yearly distance travelled per vehicle	Number of cars
1980	12 800 km	18.6 millions
1990	13 600 km	23.3 millions
1995	14 400 km	25.0 millions
1998	14 500 km	26.4 millions
1999	14 100 km	27.1 millions
2000	13 800 km	27.7 millions

Source: INRETS and CCFA.

Given the increases in both the number of cars and the average annual distance travelled in France from 1990 to 1998, it would have been necessary to reduce the unit fuel consumption of passenger cars by more than 20% in order to stabilise fuel consumption and CO_2 emissions.

The number of vehicles in use is growing due to increases in population and vehicle ownership. Vehicle ownership per 1 000 inhabitants continues to increase in all industrialised countries in Western Europe, Japan and North America (where the percentage of vehicles seemed to have reached near saturation point during the 1980s). Other countries (Korea, Turkey and Poland) are experiencing similar increases in vehicle ownership.

During the past ten years, vehicle ownership rates grew by more than 230% in Korea, 200% in Turkey, 99% in Poland, 30% in Brazil and Spain, and even 13% in France (see Table 11).

Based on these data, it seems clear that vehicle ownership will continue to increase in industrialised countries, approaching the current levels in the United States. There is also considerable short-term potential for increased vehicle ownership in populous countries such as Brazil, Argentina, Mexico – and perhaps, over the long term, in China and India.

Taken together, unit fuel consumption, average annual distance travelled and the number of vehicles in use indicate that global emissions of CO_2 from passenger cars will not decrease by 2010-15, rather they are expected to increase strongly. However, the use of economic measures such as fuel taxes, vehicle taxes based on vehicle fuel efficiency and road pricing may moderate this expected growth by reducing demand overall and encouraging the shift to more fuel efficient/low emission vehicles.

Table 11. **Vehicle ownership per 1 000 inhabitants**

	1985	1990	1995	2000	Change 1990-2000
United States	708	752	759	785	+4%
Japan	375	456	527	567	+24%
France	446	495	520	560	+13%
Germany	450	512	529	556	+9%
European Union	380	454	473	534	+18%
Spain	276	403	430	523	+30%
United Kingdom	379	454	474	512	+13%
Poland	117	160	229	318	+99%
Korea	25	71	177	238	+235%
Brazil	86	87	89	114	+31%
Turkey	27	37	65	111	+200%
China	3	5	8	11	+120%
India	3	5	6	8	+60%

Source: CCFA, July 2001.

Future trends in freight transport

Freight is largely transported by road, rail and waterway. For 30 years, while overall freight has been increasing in almost all countries in the world, the percentage of freight carried by road has also been increasing, even in industrialised countries with very dense and modern railway systems. Reasons for the success of road transport include increasing proportions of freight moved over short distances, just-in time freight deliveries, increasing demand for door-to-door freight services and greater flexibility.

Several countries, including France and Switzerland, have introduced initiatives to modify these trends by voluntary or restrictive measures.

France has encouraged rail-road transport since 1990, introducing measures such as specific links between important cities and large markets, and low prices for rail freight transport, etc. In some respects, results have been positive; the share of rail-road transport as a proportion of total rail transport climbed from 15% in 1990 to 26% in 1997. However, total freight transport by rail, including rail-road, has not increased – it has remained at the same level as 1989. The road freight share of the land transport freight task in 1999 was close to 75% in France (measured in million tonne-km), and the growth in this share has been relatively rapid (increasing from 72% at the end of 1994): only road transport has benefited from the recent sustained economic growth and related increase in the demand for surface freight transport.

Switzerland offers a useful case study. A very stringent limit of 28 tonnes was set on the total mass for trucks travelling through Switzerland by road: as a result, heavier European trucks are obliged to use rail to travel across Switzerland (for example, from Germany to Italy). In conjunction with this restriction on road transport, the railway network was improved to meet the anticipated increase in rail demand.

Even with tight constraints on road transport, the results are not very impressive:

- The share of Swiss national freight traffic by rail has decreased to the benefit of road transport.
- Total international freight traffic by road – limited by the 28-tonne restriction – climbed from 7% of the overall land transport freight traffic (rail+road) in 1984 to 26% in 1994 (Swiss Federal Department of Transport, Communications and Energy, 1996).

More recently, the Swiss limitation has caused international road freight traffic to by-pass Switzerland.

Switzerland has now decided to progressively adopt a mass limit of 40 tonnes for trucks and to impose a toll on international road freight traffic: 300 000 trucks per year will be allowed to travel through the country in 2001 and 2002, increasing to 400 000 in 2003 and 2004, and then unrestricted travel in 2005.

In 2001, the mass limit for trucks was raised from 28 tonnes to 34 tonnes and the road freight traffic toll was introduced. In 2005, the amount of the toll will be increased and the application of the 40-tonne limit generalised (Swiss Federal Department of Transport, Communications and Energy, 2000).

Some preliminary evaluations indicate that, despite the proposed road toll for through traffic, road freight transport will remain more attractive to users than rail freight (due to the nature of freight demand – including "just-in-time" requirements). This suggests that road freight through the country will increase considerably (INRETS, 1999).

Technological innovations to reduce CO_2 emissions by trucks

Future modifications are planned to reduce truck fuel consumption (*e.g.* use of more fuel-efficient diesel engines, optimising auxiliary equipment) and therefore reduce their emissions of CO_2. Currently, 40-tonne trucks use around 33 to 35 litres of diesel fuel per 100 km at a commercial speed of 70 km/h. Planned modifications aim to reduce fuel consumption to around 30 litres per 100 km at a commercial speed of 72-74 km/h.

Other changes include an expected increase in the freight carried per truck (*e.g.* through a reduction in the proportion of empty trucks using the road network).

Regulatory reform in rail and other transport sectors will be necessary to provide a balanced approach to transport growth and offer any prospect of reversing this trend. Experience to date with the impact of such restrictions on road transport has not been convincing. Further, rapid developments in e-commerce, logistics and ICT (Information and Communication Technologies) will require a whole of transport approach to policy development, rather than a modal only focus.

Conclusions: Outlook for CO_2 emissions

Based on the linear relationship between GDP and the demand for mobility-related fuels in the period 1971-99, and the assumption of continued economic growth, IEA (2000) predicts increases in total CO_2 emissions and CO_2 emissions from transport for 2010 and 2020. The IEA projections are based on a so-called "reference approach" which takes into account a range of new policies and measures taken in OECD countries to reduce the emissions of greenhouse gases, such as voluntary agreements and energy efficiency programmes. They do not take into consideration possible future or likely policy initiatives. Based on IEA forecasts, the annual growth of total CO_2 emissions from OECD countries will be 1.1% from 1997 to 2010 and 1.0% from 1997 to 2020. In addition, the share of CO_2 emissions from transport in OECD countries will increase from 27% in 1999 to 31% in 2020. Based on these same IEA projections, the worldwide increase in total CO_2 emissions will be 2.1% per year from 1997 to 2020 and the share of global CO_2 emissions from transport worldwide in 2010 and 2020 will be 22 and 23%, respectively. These forecasts highlight the expected increase in CO_2 emissions and the expectation that one-fifth of the increase in global CO_2 emissions will be generated by the transport sector.

Table 12. **Projected CO_2 emissions growth and transport share of CO_2 emissions compared to other sectors**

Region	CO_2 emission growth 1997-2020 All sectors	CO_2 emission growth rates 1997-2020 Transport	Transport share of CO_2 emissions 1997	Transport share of CO_2 emissions 2010	Transport share of CO_2 emissions 2020
World	60%	75%	21%	22%	23%
OECD countries	25%	41%	27%	30%	31%
OECD Europe	23%	41%	24%	27%	28%
OECD North America	28%	43%	30%	33%	24%
OECD Pacific	18%	32%	24%	26%	27%

Source: IEA (2000).

At the beginning of the 1990s, all industrialised countries developed models to forecast transport growth between 1990 and 2010-20, with some looking as far forward as 2040. These models were used to analyse the share of road transport and, as a consequence, the need for road transport fuels (gasoline, diesel).

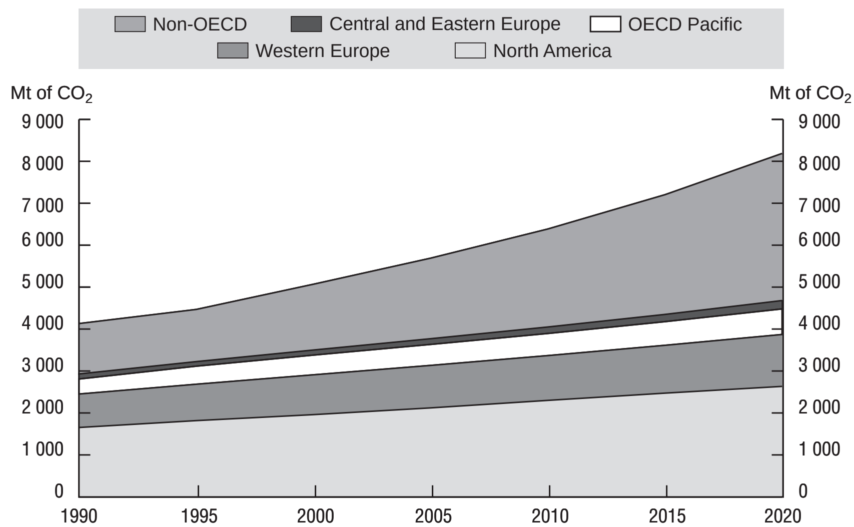
The results published by some countries in 1996-98 present large differences in forecast increases in emissions:

- The best forecasts for CO_2 emissions are for a stabilisation – or for an increase of less than 10% – in total road transport fuel consumption by 2010 compared to 1994.
- The worst forecasts for CO_2 are for a 2% annual increase, which would result in a 50% increase in road transport CO_2 emissions by 2010 compared to 1994 levels. One of the underlying projections is a doubling of road freight transport in the European Union during this period.

Analysis of the recent increase in road transport indicates a high demand, with very strong underlying forces related to economic growth and other factors. The current increase in road traffic is close to the higher end of the range estimated in the models and as a result fuel consumption is believed to be increasing by around 2% per annum in the majority of the industrialised countries. These trends predict significant continuous increases in CO_2 emissions over at least the next decade. On the basis of the underlying causes, it will be very difficult – and perhaps impossible – to modify these trends in the short term.

Based on the assumption that no drastic interventions will occur, the OECD Environment Directorate has predicted that global CO_2 emissions from transport will more than double by 2020 compared to 1990 levels (OECD, 2001) (see Figure 5).

Figure 5. **Expected increase in CO_2 emissions from transport**



Source: OECD (2001).

Passenger cars

Consumers are choosing to buy increasingly powerful vehicles, with additional equipment to enhance travel comfort (*e.g.* air conditioning, communication/navigation screens).

Rates of vehicle ownership are increasing in all industrialised countries but are still far from saturation, except, in the United States. Reasons for these increases include: increasing distances between home and workplace; lack of suitable public transport, particularly in the suburbs; commercial centres that can be most easily reached by car; and the convenience of cars for transporting people and household goods.

Technological innovations will lead to the availability of low-fuel consumption vehicles. However, the renewal of vehicle fleets will be slow – typically this takes about a decade – and there is no certainty that consumers will want to buy low-performance vehicles.

Taking these developments into account, and despite the contribution of new technologies, CO_2 emissions from passenger cars in OECD countries will not be reduced by 2010-15, when compared to 1990 emissions. Rather, they can be expected to significantly increase in some OECD countries and in some other non-OECD countries.

Freight transport

The advantages of road transport (in terms of just-in-time deliveries, door-to-door service, productivity, efficiency, etc.) are so clear that even with regulatory constraints (such as on safety, pollution and noise) and specific charges (*e.g.* tolls), road transport's share of freight transport will continue to increase relative to other modes of transport in all OECD and non-OECD countries.

The road transport share of land transport, which is nearly 75% in several OECD countries, could attain 80% in some years in these countries and nearly 100% in some developing countries, while total freight transport will continue to grow.

Technological innovations aimed at reducing the fuel consumption of trucks are feasible. However, these gains are likely to be competed away by forecast increases in demand for road transport.

Road transport is the only form of transport that has adapted quickly to recent high and sustained levels of economic growth, having been able to successfully capture increases in freight demand. However, rail transport needs major reform in many countries as well as significant investment in infrastructure, which will take considerable time and which will be fixed in geographical terms. This inflexibility in rail infrastructure makes it difficult for rail services to respond to continuous shifts in the location of freight demands associated with changing economic centres (*e.g.* factory and commercial locations).

Taking these factors into account, emissions of CO_2 by road freight transport will increase by 2010-15 in a majority of countries.

The technological modifications which are currently in progress cannot be expected to reduce or even stabilise CO_2 emissions by road transport by 2010-15.

World reserves of oil and natural gas are very large. While market prices can be expected to rise and fall somewhat in response to market conditions, substantial increases generated by market forces in the price of fuels paid by consumers – to levels that might substantially alter transport demand – would not seem likely.

As a result, substantial reduction of CO_2 emissions is unlikely in the foreseeable future despite advances in technology or potential changes in the underlying demand for transport or both. Changes in demand would seem more likely to result from increases in taxes or other changes imposed by governments or changing consumer behaviour, rather than from market-based changes in fuel prices.

This analysis supports further studies involving models that can assess the potential impact of changes imposed by governments – including new taxes and/or new regulations aimed at reducing CO_2 emissions.

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Annex A

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Appendix A

UN FRAMEWORK CONVENTION ON CLIMATE CHANGE

Within the Framework Convention on Climate Change (FCCC), there are two types of parties with different commitments: Annex I and non-Annex I parties to the FCCC:

- Annex I parties comprise the industrialised countries of the OECD and countries with economies in transition. They have to produce an annual national communication to the Conference of Parties (CoP) detailing all greenhouse gas emissions (sources and sinks) and a list of all policies and measures (with projected emissions to 2000, 2010, and 2020). They are required to promote the concept of Sustainable Development (SD) while delivering their respective Quantified Emission Limitation and Reduction Objective (QUELRO).
- Non-Annex I parties (developing and newly industrialised countries) are the rest of the world (*e.g.* G77 + China). Non-Annex I parties are required to compile national communications starting from 1997 and as often as possible thereafter.

Annex II countries are the countries listed in Annex II in the Climate Convention (comprising the OECD countries as of 1992 and the EU). Annex II parties are to provide new and additional funding to the Global Environmental Facility (GEF) to meet the fully agreed costs of advancing the implementation of existing commitments in the Protocol. In addition, resources are encouraged to aid in the transfer of technology to non-Annex I parties, through both bilateral and multilateral channels.

List of Annex I parties

Australia
Austria
Belarus
Belgium
Bulgaria
Canada
Croatia
Czech Republic
Denmark
Estonia
European Union
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Japan
Latvia
Liechtenstein
Lithuania
Luxembourg
Morocco
Monaco
Netherlands
New Zealand
Norway
Poland
Portugal
Romania
Russian federation
Slovak Republic
Slovenia
Spain
Sweden
Switzerland
Turkey
Ukraine
United Kingdom
United States

Appendix B

CO_2 EMISSIONS FROM ROAD TRANSPORT

Million tonnes of CO_2

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Change Base Year-1999 (%)	National CO_2 emissions target under the Kyoto Protocol compared to base year level
Australia	54.907	52.869	54.027	55.174	56.745	58.247	60.150	61.280	62.265	63.881	16.3%	8%
Austria	14.355	15.839	15.832	16.078	16.027	16.272	16.313	16.664	16.011	16.566	15.4%	–13%
Belgium	19.601	19.790	20.526	21.039	21.522	21.594	22.013	22.287	22.971	23.287	18.8%	–7.50%
Bulgaria	5.835	3.415	3.509	3.968	3.675	3.964	4.001	4.065	5.048	5.216	–24.3%	–8%
Canada	95.940	92.921	94.649	97.024	101.717	104.389	106.171	109.955	112.299	115.275	20.2%	–6%
Czech Republic	7.000	6.220	7.797	7.902	8.620	7.288	9.646	9.876	10.147	10.636	51.9%	–8%
Denmark	9.409	9.824	9.957	10.072	10.574	10.693	10.825	11.032	11.097	11.349	20.6%	–21%
Finland	10.967	10.649	10.629	10.368	10.741	10.585	10.321	10.895	11.006	11.207	2.2%	0%
Former USSR	219.486	295.764	224.857	176.531	152.038	139.721	133.998	130.506	144.418	140.793	–35.9%	0% for Russia and Ukraine, –8% for Estonia, Latvia and Lithuania
France	109.566	112.357	115.137	116.130	117.678	118.722	118.751	121.169	125.624	128.057	16.9%	0%
Germany	151.312	154.738	157.983	162.668	160.137	162.634	164.012	164.917	168.222	173.789	14.9%	–21
Greece	11.710	12.552	12.853	13.151	13.335	13.765	14.425	14.760	15.508	15.786	34.8%	25%
Hungary	7.713	6.914	6.751	6.793	6.624	6.844	6.843	7.274	8.160	8.658	22.5%	–6%
Iceland	0.539	0.557	0.552	0.552	0.564	0.551	0.607	0.529	0.560	0.579	7.5%	10%
Ireland	4.654	4.839	5.258	5.235	5.460	5.648	6.570	6.921	8.204	9.076	95.0%	13%
Italy	93.108	94.991	100.125	102.153	101.880	104.021	104.551	106.019	109.701	110.853	19.1%	–6.50%
Japan	179.722	186.926	194.616	194.674	205.105	209.488	216.698	221.229	220.772	223.954	24.6%	–6%
Korea	31.916	36.651	41.634	46.962	53.030	60.222	65.958	65.101	53.950	59.248	85.6%	
Luxembourg	2.641	3.142	3.437	3.481	3.543	3.368	3.463	3.664	3.829	4.129	56.3%	–28%
Mexico	84.196	90.976	92.394	94.362	95.912	92.422	89.858	92.150	94.719	96.219	14.3%	
Netherlands	24.032	24.091	25.168	25.719	26.100	26.824	28.603	28.962	28.609	28.706	19.4%	–6%
New Zealand	5.955	5.989	6.080	6.073	6.229	6.397	6.418	6.561	6.629	6.726	12.9%	0
Norway	7.738	8.124	8.255	8.663	8.609	8.884	9.333	9.317	9.489	9.795	26.6%	1%
Poland	17.977	19.520	20.279	19.840	20.756	21.533	24.670	26.225	25.879	29.014	40.1%	–6%
Portugal	9.199	9.916	10.831	11.402	11.987	12.469	13.265	13.808	15.032	15.797	71.7%	27%
Republic Slovak	2.921	2.454	2.774	2.653	3.189	3.615	3.375	3.409	4.058	4.123	41.1%	–8%
Romania	10.768	9.099	8.339	6.977	7.600	6.983	10.134	9.742	9.545	7.443	–18.5%	–8%
Slovenia	2.610	2.462	2.526	3.065	3.428	3.823	4.346	4.557	4.006	3.799	45.5%	–8%
Spain	53.692	56.603	59.862	59.092	61.391	62.353	66.143	66.899	73.455	77.477	44.3%	15%
Sweden	18.136	17.943	18.670	18.414	19.157	19.242	19.107	19.249	19.543	19.970	10.1%	4%
Switzerland	14.139	14.586	14.940	13.958	14.441	14.151	14.214	14.708	14.848	14.711	4.0%	–8%
Turkey	25.622	24.631	24.953	29.875	28.439	31.226	32.895	29.991	27.142	29.903	16.7%	
United Kingdom	108.569	107.809	109.271	110.558	111.245	110.232	114.519	115.983	115.278	114.403	5.4%	–12.50%
United States	1 141.462	1 126.666	1 161.280	1 187.042	1 230.029	1 266.172	1 296.944	1 325.327	1 370.434	1 412.922	23.8%	–7%
15 EU countries	640.951	655.083	675.540	685.561	690.777	698.422	712.881	723.229	744.090	760.452	18.6%	–8%
Non-OECD countries	899.565	1 011.781	973.990	976.459	995.418	1 047.508	1 106.930	1 152.559	1 193.493	1 218.633	35.5%	
OECD countries	2 318.699	2 331.088	2 406.520	2 457.108	2 530.784	2 589.851	2 656.663	2 706.159	2 765.442	2 846.097	22.7%	
WORLD	3 218.263	3 342.869	3 380.509	3 433.567	3 526.203	3 637.359	3 763.593	3 858.719	3 958.935	4 064.729	26.3%	

Source: IEA (2001).

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