Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change

Economic Evaluation of Emissions Reductions in the Transport Sector of the EU

Bottom-up Analysis

UPDATED

Final Report (updated version)
March 2001

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Contribution to a Study for DG Environment, European Commission by Ecofys Energy and Environment, AEA Technology Environment and National Technical University of Athens

Preface

This report considers options to reduce greenhouse gas emissions from transport, and uses a 'bottom up ' approach to assess the cost-effectiveness of options and the reductions it might achieve. In assessing potential reductions, it draws on work on future transport demand completed by the National Technical University of Athens for this project using the PRIMES energy model. The report should be read in conjunction with those from NTUA. The report focuses on emissions of CO_2, with some consideration of N_2O emissions; emissions of HFCs from mobile air conditioning and refrigerated transport were considered in a separate part of the study by Ecofys (Economic Evaluation of Emission Reductions of HFCs, PFCs and SF6 in Europe), and are only briefly summarised here.

On its way to its current form this report has received significant input from a considerable number of experts. In particular, a panel of experts in Brussels discussed a draft version of the NTUA PRIMES report on transport on November 23, 1999 (see Appendix 7 for a list of names), and a draft version of this report at a workshop on March 30, 2000. The experts made a number of specific and more general comments and suggestions. The author would like to thank these people for their valuable inputs into this study. For this "Final Report" it was attempted to consider their suggestions wherever possible.

This is a revised version of the final report that was posted to the EU website in December 2000. The revisions are to reflect updated 1990 figures from the UNFCC.

EXECUTIVE SUMMARY

The main greenhouse gas emissions associated with transport are CO_2 emissions that are a direct result of the combustion of vehicle fuels (petrol, diesel, aviation kerosene etc). N_2O emissions from petrol cars equipped with 3-way catalytic converters are higher than from non-catalyst cars and could constitute a growing source.

Within this study, baseline projections of energy demand are taken from the Primes model baseline scenario defined for the 'Shared Analysis' project 1999. This excluded the impacts of the voluntary agreement reached with European (ACEA), Japanese (JAMA) and Korean (KAMA) car manufacturers[1] to reduce the average CO_2 emissions for all new cars. The impact of this and the agreements with the non-European producers has been included in this study. The table below shows the emissions in 1990 [Primes, 1999] for the transport sector and two baseline projections. Under the baseline, transport emissions are projected to grow by 35% by 2010, with the ACEA agreement the growth is 25% due to the smaller growth in emissions from passenger transport[2].

Baseline Trends in CO_2 Emissions from Transport in the EU in 1990-2010

	1990 emissions	2010 baseline	2010 baseline with ACEA agreement	Change 1990-2010	Change 1990-2010 with ACEA agreement
	Mt CO_2	Mt CO_2	Mt CO_2	% change	% change
Total (passenger)	524	718	608	37%	22%
Total (freight)	245	412	310	33%	33%
Total (all)	**769**	**993**	**918**	**35%**	**25%**

Note: Air passenger transport also includes air freight. See footnote 2 for an update.
Source: PRIMES

There are three main ways in which CO_2 emissions from transport can be reduced:

- **Operational** - reducing energy use and emissions per vehicle km (vkm) driven.
- **Strategic** - optimisation of the vehicle use, reducing total vehicle km per passenger km (pkm) or per tonne km (tkm).
- **Demand** - reducing the overall demand (pkm or tkm) for travel.

In this 'bottom up' study of available options we have focused on 'operational' solutions to reduce energy use and emissions per vehicle kilometre driven. For these options, quantitative data on costs and reductions are available allowing the assessment of cost-effectiveness in terms of €/tonne CO_2. The table below

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[1] As American car manufacturers are all present in the EU, the ACEA agreement covers the emissions from these cars. For simplicity, in this report the ACEA/JAMA/KAMA agreement is referred to as the "ACEA agreement".

[2] However, in the most recent baseline (see the Green Paper of the European Commission *"Towards a European strategy for the security of energy supply"*, COM(2000) 769, November 2000), the projections of transport emissions have increased by 184 Mt of CO_2 implying that the growth of CO_2 from transport would be 41% instead of 25% by 2010. This increase is due to higher projected growth in truck transport as well as in aviation. These latest numbers have not been included in this analysis.

summarises the costs and savings from different options, assuming no interaction between measures.

Cost of different options to reduce greenhouse gas emissions from transport sector in the EU

Name measure	**Subsector**	**EU15 Emission reduction potential**	**Specific costs**
		kt CO2	Euro/tCO2
Rolling Resistance	Freight	10882	-72
Engine improvement	Freight	3733	-64
Aerodynamics - Cab Roof Fairing	Freight	2682	-51
Aerodynamics - Cab Roof Deflector	Freight	1739	-47
Mobile air conditioning: leakage red.	Mob Airci	6627	6
Lightweight Interior components - Petrol cars	Passenger carsPetrol	1128	8
Variable Valve Lift Timing + Cylinder Deactivation	Passenger carsPetrol	22768	19
Driver Training - Heavy Goods Vehicles (HGV) Drivers	Freight	10871	19
Transport refrigeration: leak reduction	Refrigeration	2787	29
Mobile air conditioning: recovery	Mob Airci	3534	31
Basic package - Diesel cars	Passenger cars Diesel	1603	41
Lightweight Interior components - Diesel cars	Passenger cars Diesel	198	81
Petrol to Diesel shift	Passenger carsPetrol	7803	82
Advanced Gasoline Direct Injection (advanced: "DISC")	Passenger carsPetrol	19025	92
Basic package - Petrol cars	Passenger carsPetrol	9119	122
Lightweight structure - Petrol cars	Passenger carsPetrol	9906	217
Lightweight structure - Diesel cars	Passenger cars Diesel	1736	327
Total technical emission reduction potential (Mt of CO2-eq.)	**116**		

’Strategic’ and ’Demand’ based solutions generally rely on influencing behaviour, and can use a wide variety of methods to do so. Data are becoming available on the impact of these ’non-technical’ type measures, but are often not complete enough to allow the estimation of the cost-effectiveness of options. Thus extrapolation of costs and impacts across the EU cannot be done with any accuracy.

In this bottom-up study, we have identified 73 MtCO$_2$ eq. of savings in passenger cars, 30 MtCO$_2$ eq. in freight and 13 MtCO$_2$ eq. from improvements in mobile air conditioning. The top-down projections (from the Primes model) for the baseline already include some reductions from improved fuel efficiency. For cars, the reductions from the ACEA agreement are larger than the savings identified in this study. It is therefore assumed that the identified measures, together with others not identified, will be implemented as part of the agreement. The ‘with measures’ projection for cars is therefore taken to be the baseline with the ACEA agreement. For freight, the reductions included in the baseline are smaller than the measures identified in the study and the ‘with measures’ projection includes the additional reductions from this study.

Baseline and 'With Measures' Trends in CO_2 Emissions from Transport in the EU, 1990-2010

	1990 emissions	2010 baseline	2010 baseline with ACEA agreement	2010 'with measures'	Change 1990-2010 with measures
	CO_2 (Mt)	CO_2 (Mt)	CO_2 (Mt)	CO_2 (Mt)	% change
Total (passenger)	500	683	608	608	22%
Total (freight)	233	310	310	280	20%
Total (all)	**734**	**993**	**918**	**888**	**21%**

An analysis of air conditioning and catalytic converters estimates that they could increase greenhouse gas emissions by some 25 g/km (CO_2 equivalent) per vehicle. It seems that mobile air conditioning could increase the nitrous oxide emissions further. Fortunately it seems that lower sulphur content of fuels would reduce nitrous oxide emissions to some extent.

Due to data constraints, this study focuses on road transport. Some preliminary analysis is undertaken for air transport. As greenhouse gas emissions from railways and inland navigation are fairly small, they have not been analysed as part of this study, except in terms of modal shifts.

CONTENTS

1 INTRODUCTION

Reduction of fuel consumption and associated greenhouse gas emissions has recently become a higher priority with governments, the public and vehicle manufacturers alike as concerns over air quality and global warming grow. At present transport is a significant contributor to CO_2 emissions and demand is rising. EU transport CO_2 emissions were 752 Mt in 1995 compared to 695 Mt in 1990 and are projected to keep on rising.

The increasing traffic demands also have other environmental implications in addition to CO_2 emissions - in particular urban air pollution is currently of great concern. Regulated vehicle emissions include carbon monoxide, particulate matter (PM_{10}), nitrogen oxides and hydrocarbons. These are coming under increasingly stringent limits, and, hence, significant reductions in such pollutants are predicted. However, transport-related air quality "hotspots" will remain in some local areas with the exception of PM_{10} which is predicted to remain a problem at a larger scale.

This chapter considers options for reducing greenhouse gas emissions from the two main sources of transport related emissions, passenger cars and freight vehicles. Between them these sources account for about three-quarters of transport related emissions. The other main source, aviation is also discussed, but minor sources such as rail, and inland and maritime navigation are not considered. Emissions of the ‘industrial’ greenhouse gases (HFCs and PFCs) associated with the use of mobile air conditioning are not considered here, as they have been examined in another part of the study which focused on these gases. In Appendix 1, an analysis is presented of emissions from the use of mobile air conditioners and catalytic converters. The relevant part of the study on industrial gases are included in this appendix.

Current emissions estimates for transport sources are presented and discussed in Section 2, and projections in Section 4. International reporting requirements (IPCC, 1997) at present stipulate that emissions associated with international aviation and maritime journeys should be reported separately, as these are currently not allocated to any particular country. Emissions associated with electricity generation for powering electric train lines, are reported under the electricity generation heading and not under ‘transport’, and it is thus not possible to identify these emissions separately in national emissions estimates.

2 EMISSIONS

2.1 EMISSION MECHANISMS

The main greenhouse gas emissions associated with transport are CO_2 emissions that are a direct result of the combustion of vehicle fuels (petrol, diesel, aviation kerosene etc). There are also emissions of nitrous oxide (N_2O) and methane from combustion of the fuel (Table 2.1), which are minor compared to emissions of CO_2 (typically only 2% for cars after allowing for the relative global warming potentials of the two gases). However N_2O emissions from petrol cars equipped with early 3 way catalytic converters are higher than from non-catalyst cars, and could constitute a rapidly growing source of N_2O emissions. Catalytic converters also slightly increase CO_2 emissions, and thus while helping substantially reduce emissions of urban air pollutants and improve air quality, unfortunately lead to a significant (15%) increase in greenhouse gas emissions per km (Table 2.1).

It should be noted however that the data in Table 1.1 was derived in 1996 and is based on the first generation of three way catalysts that were introduced. Since then catalyst performance has improved and it seems likely that N_2O emissions from cars with newer catalysts do not show such a significant increase. This is discussed further in Section 3.2.1.5.

Table 2.1 Typical emissions factors for modern European petrol cars (1996)

	CO_2	N_2O	CH_4	CO_2	N_2O	CH_4	Total
	g/km			g CO_2eq/km			
Without 3 way catalyst	190	0.005	0.07	190	1.55	1.47	193
With 3 way catalyst	205	0.05	0.02	205	15.5	0.42	221

Source: IPCC, 1997

In the case of aviation, other mechanisms also need to be considered. Subsonic aircraft emit gases and particles (carbon dioxide, water vapour (H_2O), nitrogen oxides ($NO_{x)}$ and sulphur oxides (SO_x)) into the upper layers of the atmosphere, the upper troposphere and lower stratosphere. These emissions have an impact on atmospheric composition, altering the concentration of greenhouse gases, including CO_2, ozone (O_3), and methane, and triggering formation of condensation trails (contrails).

The atmospheric chemistry related to these emissions is complex with a number of reactions and interactions occurring. In the upper troposphere, the NO_x emissions are more effective at producing ozone (which acts as a greenhouse gas) than at lower altitudes and furthermore the increases in ozone at higher altitudes are more effective at increasing radiative forcing than increases at lower altitudes. SO_x and water emissions in the stratosphere tend to deplete ozone, partially offsetting the NO_x induced increases, but this effect has yet to be quantified. The NO_x emissions are expected to decrease concentrations of the greenhouse gas methane. Contrails tend to warm the Earth's surface, similar to thin high clouds. Overall, their radiative effect depends on their global cover, and their optical properties, which in turn depend on the particles emitted by aircraft or formed in the air craft plume and the atmospheric conditions (IPCC, 1999).

2.2 EMISSION IN EU-15

Table 2.2 shows national estimates provided to UNFCCC of transport related $CO_{2,}$ N_2O and CH_4 emissions. These figures exclude greenhouse gas emissions due to leakage of refrigerants from the use of mobile air-conditioning equipment and refrigerated transport. (These emissions and options to reduce them are summarised in Appendix 2.) The transport category includes on and off road transport and domestic aviation and inland maritime transport. Emissions from fuel sold to any air or marine vessel engaged in international transport (international bunker fuels) do not currently count towards countries national emissions totals and are reported separately to the UNFCCC as bunker fuels (Table 2.3). Transport related CO_2 emissions in the EU rose by 8% between 1990 and 1995; N_2O emissions rose by 60% over the same period, reflecting the increase in the number of petrol cars with catalytic converters. As catalytic converters lead to a decrease in CH_4 emissions, these fell (by 12%).

The UNFCCC emissions data do not provide a breakdown of emissions by transport type, but an estimate is available from the PRIMES model (Table 2.4). Within the PRIMES model, aviation includes both national and international flights from the EU[3], but international marine navigation is not included. The total PRIMES estimate of emissions cannot therefore be compared directly to the estimates shown in Table 2.2 and Table 2.3.

Table 2.4 shows that in 1995 cars were estimated to account for almost 50% of the EU transport emissions of CO_2, and road freight (trucks) another 30%. Improvements in fuel efficiency targeted on these two transport modes are therefore likely to have the largest effects on reducing overall transport CO_2 emissions. Since aviation also accounts for a significant portion (12%) of all EU transport CO_2 emissions, it should also be considered.

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[3] According to the Guidelines for National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change (IPCC), emissions based upon fuel sold to ships or aircraft engaged in international transport should not be included in national totals, but reported separately. Thus, emissions from domestic aviation should be included. Unfortunately the data on split between domestic and international aviation is not currently available. The implicit assumption made in this report is that the growth rates of international and domestic aviation are the same. As this is not likely to be the case (as domestic aviation is likely to grow slower than international aviation) there is an in-built bias in this report. Eurocontrol (2000) projects that between 1999-2007 departures and arrivals of domestic aviation grow annually by 3,8% but by 5,3% internationally. It would be vital to get a better understanding of the split between domestic, intra-EU and international flights.

Table 2.2 Transport Greenhouse Gas Emissions by Member States for 1990 and 1995.

	CO_2 (Mt)		% Change	N_2O (Mt CO_2 eq)		% Change	CH_4 (Mt CO_2 eq)		% Change	Total (Mt CO_2 eq)		% Change	Total per capita (t CO_2 eq/cap)	
	1990	1995		1990	1995		1990	1995		1990	1995		1990	1995
Austria	14	16	*12%*	0.3	0.6	*100%*	0.1	0.0	*-26%*	14	16	13%	1.85	2.00
Belgium	20	22	*9%*	0.3	0.3	*0%*	0.2	0.2	*3%*	20	22	9%	2.05	2.21
Denmark	10	11	*9%*	0.0	0.3		0.0	0.0	*0%*	11	12	11%	2.05	2.24
Finland[1]	12	11	*-7%*	0.6	0.6	*0%*	0.1	0.1	*-9%*	12	12	-6%	2.51	2.29
France	123	134	*9%*	1.2	2.2	*75%*	0.5	0.4	*-12%*	125	137	10%	2.20	2.35
Germany	162	173	*7%*	3.1	5.3	*70%*	1.3	0.6	*-54%*	167	180	8%	2.10	2.21
Greece	15	17	*11%*	0.3	0.3	*0%*	0.1	0.1	*18%*	15	17	12%	1.52	1.65
Ireland	5	6	*27%*	0.0	0.3		0.0	0.0	*58%*	5	6	29%	1.42	1.78
Italy	95	109	*14%*	1.2	1.9	*50%*	1.3	1.6	*25%*	97	112	15%	1.72	1.96
Luxembourg[2]	3	3	*31%*	0.0	0.0		0.0	0.0	*0%*	3	3	31%	6.95	8.66
Netherlands	29	32	*12%*	1.6	2.2	*40%*	0.2	0.1	*-21%*	30	34	14%	2.02	2.21
Portugal[3]	14	17	*20%*	0.3	0.3	*0%*	0.1	0.1	*-3%*	14	17	20%	1.45	1.73
Spain	58	64	*10%*	0.6	0.9	*50%*	0.3	0.3	*-4%*	59	65	11%	1.52	1.67
Sweden	19	19	*4%*	0.9	0.9		0.5	0.4	*-12%*	20	21	4%	2.33	2.34
United Kingdom	116	117	*1%*	1.2	2.8	*120%*	0.7	0.5	*-19%*	118	121	2%	2.05	2.06
EU15	**695**	**752**	***8%***	**11.8**	**18.9**	***60%***	**5.2**	**4.6**	***-12%***	**711**	**776**	**9%**	**1.95**	**2.09**

[1] Decline in emissions due to a severe economic slump in Finland in the early 1990s.
[2] Per capita figures for Luxembourg are distorted by fuel purchases made in Luxembourg in vehicles from other countries
[3] Portugal data not available for 1995; 1994 data substituted.

Source: UNFCCC, 1999.

Table 2.3 International Air and Maritime ('Bunker Fuel') Greenhouse Gas Emissions by Member States for 1990 and 1995[1]

Member State	**CO_2 (Mt)**		*% Change* [4]	**N_2O (Mt CO_2 eq)**		*% Change*	**CH_4 (Mt CO_2 eq)**		*% Change*	**Total (Mt CO_2 eq)**		*% Change*
	1990	**1995**		**1990**	**1995**		**1990**	**1995**		**1990**	**1995**	
Austria	1	1	*37%*	0.003	0.003	*0%*				1	1	*37%*
Belgium	16	16	*-1%*							16	16	*-1%*
Denmark	5	7	*42%*							5	7	*42%*
Finland	3	2	*-36%*	0.37	0.25	*-33%*	0.03	0.02	*-23%*	3	2	*-35%*
France	15	17	*12%*	0.08	0.07	*-12%*				16	17	*12%*
Germany	20	20	*2%*	0.19	0.19	*0%*	0.01	0.01	*0%*	20	20	*2%*
Greece	10	14	*33%*	0.19	0.25	*33%*	0.03	0.04	*42%*	11	14	*33%*
Ireland	1	2	*29%*							1	2	*29%*
Italy	12	13	*7%*	0.19	0.22	*17%*	0.02	0.02	*0%*	12	13	*7%*
Luxembourg	0.1	0.2	*75%*							0	0	*75%*
Netherlands	40	45	*10%*							40	45	*10%*
Portugal[2]	2	2	*-10%*	0.01	0.01	*0%*	0.04	0.04	*-17%*	2	2	*-10%*
Spain												
Sweden	4	5	*28%*							4	5	*28%*
United Kingdom	21	26	*22%*	0.27	0.32	*17%*	0.07	0.08	*15%*	22	26	*22%*
EU15	**151**	**169**	***11.9%***	**1.30**	**1.30**	***0.5%***	**0.2**	**0.2**	***3.7%***	**153**	**171**	***12%***

[1] Blanks in Table indicate emissions are not estimated.
[2] Portugal data not available for 1995; 1994 data substituted.

Source: UNFCCC, 1999.

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[4] Rounding of the Mt figures means that these changes may not be apparent from the table.

Table 2.4 PRIMES breakdown of CO_2 emissions by transport type (EU14*, 1995)

Transport Mode	Mt CO_2	% Total CO_2
Cars - Petrol	324	40.5%
Cars - Diesel	66	8.3%
Cars - Other	7	0.9%
Buses	28	3.5%
Motorcycles	6	0.8%
Trucks – Diesel	230	28.7%
Trucks – Other	13	1.7%
Trains	8	1.1%
Aviation**	96	12.0%
Inland Navigation	20	2.6%
Total	**800**	**100.0%**

***** Luxembourg not included. **Aviation includes both domestic and international aviation

Source: PRIMES.

3 EMISSION REDUCTION OPTIONS

3.1 INTRODUCTION TO THE MEASURES

There are three main ways in which CO_2 emissions from transport can be reduced:

- **Operational** - reducing energy use and emissions per vehicle km (vkm) driven.
- **Strategic** - optimisation of the vehicle use, reducing total vehicle km per passenger km (pkm) or per tonne km (tkm).
- **Demand** - reducing the overall demand (pkm or tkm) for travel.

A number of policy levers are available for implementing measures in these three categories, including:

- Pricing policies and incentives
- Taxes
- Regulation
- Infrastructure
- Information and public awareness initiatives
- Voluntary agreements
- Institutional frameworks

In this 'bottom up' study of available options we have focused on 'operational' solutions to reduce energy use and emissions per vehicle kilometre driven. For these options, quantitative data on costs and reductions are available allowing the assessment of cost-effectiveness in terms of €/tonne CO_2.

Operational or technological measures to improve vehicle energy use include:

- Engine efficiency improvements
- Major engine changes
- Weight reduction
- Friction & drag reduction
- Alternative fuels

The first four of these options are considered in Section 3.2 for cars and Section 3.5 for freight. As far as alternative fuels are concerned, it is currently envisaged that petrol and diesel will dominate car propulsion in the short to medium term, and significant cost-effective penetration of these measures is not forecast before 2010. Only a brief analysis of these measures is undertaken in Section 3.6.

’Strategic’ and ’Demand’ based solutions generally rely on influencing behaviour, and can use a wide variety of methods to do so. Data are becoming available on the impact of these ’non-technical’ type measures, but are often not complete enough to allow the estimation of the cost-effectiveness of options. Furthermore many options are specific to certain types of area, with their effectiveness influenced by a number of very local parameters. Thus even where quantitative data to calculate cost-effectiveness are available, extrapolation of costs and impacts across the EU cannot be done with any accuracy. An overview of the types of measures available and indications of the cost-effectiveness of such options is given in Section 3.3.

Transport statistics clearly indicate a steady upward trend in both passenger and freight demand. While in the past, demand has been strongly linked to growth in GDP and income, it is becoming increasingly recognised that it is important to look at this relationship more closely. Gaining a better understanding of the drivers of transport demand (see Box) allows ways in which it may be possible to decouple transport growth from income growth to be identified. In this respect ‘non-technical’ strategic and demand based solutions are likely to be very important in the longer term.

Transport Demand

Passenger Demand

Transport statistics show that income and transport demand have been strongly related in the past, with personal travel often growing directly in proportion to income. However this could change in the future as car ownership saturates leading to a decline in the elasticity of demand.

The main increase in passenger vehicle kilometres seems to arise not from people travelling more often, but from travelling further and with greater use of the private car. For example, in the UK the distance travelled per year by the average person has increased by more than 40% over the last twenty years (from 7,578 km per person per year in 1975/6 to 10,726 km in 1995/7) (SACTRA, 1999). The majority of this distance is travelled by car, and the proportion travelled by car has also increased (from 67% to 78% over the same period). The majority (67%) of the distance travelled by private road transport was on ‘personal’ trips (visiting friends, shopping etc), with commuting accounting for only 19%. Commuting accounted for almost 28.5% of public transport journeys.

The effect of price on transport demand is usually smaller that income effects, but is still large enough to be significant. Car price affects vehicle ownership and fuel prices affects traffic volumes and fuel consumption. It also seems that other factors, primarily journey time (which can be considered to have a cost to individuals) affect transport demand. Thus as journey times decrease (e.g. due to faster transport routes such as motorways), transport demand increases.

Freight Demand

In most European Countries there has, for several decades, been a close relationship between road freight demand and economic growth, but in some European countries it appears that these trends have begun to diverge. Recent research in the Netherlands, suggests that around half of all freight traffic growth can be explained by economic growth, and that the remainder appears to be due to changes in spatial geography and logistical systems. For example, the concentration of production and distribution facilities, expansions in market both at a national and European level, and a shift away from bulk commodities which are usually transported over short distances to higher value commodities requiring longer hauls.

This finding was backed up by a study which examined the reason for growth in freight transport in 5 European countries between 1985 and 1995 (REDEFINE, 1999). This found that the single most important contributor to increased road freight demand was the average length of haul, which resulted in about a 50% increase in tonne-kilometres. The increase in vehicle kilometres was substantially less than this as it was partially offset by the use of heavier vehicles, and a reduction in the level of empty running.

3.2 TECHNICAL MEASURES – CARS

3.2.1 Description of Options

3.2.1.1 Engine Efficiency Improvements

Hi-Speed Engine with Variable Valve Lift & Timing (VVLT)

In petrol fuelled cars, Variable Valve Timing and Lift can be used to reduce the engine size required to achieve the desired maximum power level by allowing more optimum valve timing and lift at each engine speed. It can also be used to reduce throttling losses independent of its effect on engine size. Current uses of this technology include the Mitsubishi "MIVEC" (**M**itsubishi **I**nnovative **V**alve Timing and Lift **E**lectronic **C**ontrol) system which also uses Cylinder Deactivation. Other manufacturers such as Mercedes-Benz, Honda, Porsche and Alfa-Romeo have also introduced VVLT in some of their models.

Compared to vehicles with 2-Valve heads and no fixed valve timing, reductions in CO_2 per km of 6.9% are estimated (Austin *et al*, 1999), which is comparable to those estimated by OTA (1995). When combined with cylinder deactivation, reductions in CO_2 per km of 14.7% are estimated (Austin *et al*, 1999)[5].

Cylinder Deactivation at Idle and Part Load

This technology, which is only for petroleum fuelled engines, is still being developed but has already been implemented by some manufactures together with VVLT, (e.g. the Mitsubishi MIVEC system detailed above). By deactivation of some cylinder intake valves at low power levels, the other cylinders have to operate at higher load; this leads to a higher level of operational efficiency. The level of savings which can be achieved depends on the number of cylinders in the vehicle, how many can be deactivated and the driving and idling conditions during which the cylinders can be deactivated. There are some significant differences in opinion among manufacturers regarding the operating conditions during which cylinder deactivation could be activated while maintaining commercially acceptable drivability and noise, vibration and harshness levels, but savings potentials will be limited to some extend by comfort and emission considerations.

Cylinder deactivation was estimated to reduce CO_2 emissions by 11.3% (Austin *et al*, 1999)[6].

Continuously Variable Transmission (CVT)

Continuously Variable Transmission (CVT) allows flexibility in matching power demand with the optimum region of the engine map. In concept, the CVT could be used to maximise fuel economy under part-load conditions, while simultaneously providing maximum acceleration performance at wide-open throttle. In addition this would enable a smaller engine to achieve the same acceleration performance as a

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[5] A reviewer pointed out that potential savings from VVT are in the range of 5 – 7%, and the estimate of 6.9% is therefore optimistic. They also believed that the potential for the saving when combined with cylinder deactivation was an overestimate, as once cylinder deactivation is in place the remaining cylinders will run at relatively high load, and other measures to improve low load fuel consumption will further improve fuel efficiency only marginally.

[6] One reviewer believed that this was too optimistic an estimate of savings and that while an aggressive shut off schedule might achieve a 10% reduction, comfort and emissions considerations would limit this to about 7%.

conventional transmission and a larger engine, compounding the potential fuel economy benefits of the CVT. A disadvantage of CT is significantly high internal friction. It is applicable in both petrol and diesel engine vehicles.

The CVT design has been in use in a simple form in a number of current vehicles since 1987 (e.g. the Honda Civic and Subaru Justy in the US). Poulton (1997) has reported that other manufacturers such as Ford, Nissan and Rover are now also using CVT technology in some of their cars.

Currently CVT fuel economy is at best approximately the same as that of a manual gearbox, and while some believe that it will never exceed the fuel economy achieved by a good manual gearbox, others expect it to improve in the future, and exceed manual gearbox performance. A Canadian study (Austin *et al*, 1999) which examined CVT assumed that theoretical engine size reduction at constant performance would not be achieved because of speed ratio and efficiency limitations. They estimated that CO_2 per km could be reduced by 10.2% compared to US automatic transmission systems, which account for the vast majority of vehicles in that country. Potential improvements in Europe are assumed to be 50% of this (i.e. 5.1% reduction in CO_2/km) to account for improvements relative to the more efficient manual transmission which predominates in Europe.

3.2.1.2 Major Engine Changes

Petrol to Diesel Shift

Diesel engines are more fuel efficient than conventional gasoline engines because they do not require throttling of the intake charge, they are able to use a higher compression ratio, and, because they run leaner, they have a thermodynamically more favourable ratio of specific heats. Disadvantages include the higher particulate emissions of diesel relative to petrol engines and the difficulties in using catalytic converters with them, although there are a number of technologies being developed in this area to overcome these problems.

Diesel versions of the same model car can have up to 30% lower CO_2 emissions. For example, CO_2 emissions for similar specification petrol and diesel versions of the VW Golf Comfortline are (DETR, 2000):

Petrol 1.6 l Euro 3-D, 74 kW 5-Gear, 182 g/km CO_2
Diesel 1.9 l TDI Euro 3-D, 66 kW 5-Gear, 135 g/km CO_2.

These CO_2 emission rates are the results of test required under EU Directive 93/116/EC for all new cars, and are for a combined test cycle (urban and extra urban/highway)[7]. Improvements may however vary across different makes and models of cars, and the differential may be reduced as the efficiency of petrol engines is improved, particularly as GDI engines are introduced. For this evaluation, an

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[7] The urban test cycle is carried out from a cold start, and consists of a series of accelerations, steady speeds, decelerations and idling. Maximum speed is 50 km/h, average speed 19 km/h and the distance covered is 4 km. The extra-urban cycle is conducted immediately following the urban cycle and consists of roughly half steady-speed driving and the remainder accelerations, decelerations, and some idling. Maximum speed is 120 km/h, average speed is 63 km/h, and the distance covered is 7 km. The figure presented is for the urban and the extra-urban cycle together, and is therefore an average of the two parts of the test, weighted by the distances covered in each part.

average value of 20% reduction in CO_2 emissions per km is taken for switching from conventional petrol engines to diesel engines[8].

The diesel engine car proportion of the market is steadily increasing. There is a limit, however, to the extent of the change in proportions of diesel to petroleum fuelled vehicles, as beyond a certain point it becomes uneconomical to change the relative fraction of petroleum to diesel in the oil refining process. Very large increases in diesel consumption could increase emissions from refining due to the need to produce diesel from heavier products and increased use of post processing units such as hydro desulphurisation. It is unlikely that this point would be reached with the increases in diesel penetration considered in this report.

GDI Engine

Conventional petrol engines use fuel injection. Multi-Point Injection (MPI), where the fuel is injected to each intake port, is one of the most widely used systems. In a Gasoline Direct Injection Engine, petroleum is directly injected into the cylinder as in a diesel engine, and injection timings are precisely controlled to match load conditions (Mitsubishi Motors, 2000). This allows:

a) Extremely precise control of fuel supply, achieving a better fuel efficiency than in diesel engines by enabling combustion of an ultra-lean mixture supply.
b) Very efficient intake and relatively high compression ratio, which delivers both high performance and responses.

One company (Mitsubishi Motor Corp.) introduced GDI engine models in Japan in August 1996, and by the end of 1997 they accounted for 70% of the passenger models on offer (not including mini-cars). Mitsubishi aim to increase this to 85% by 2000 and to 100% by 2010. The release of GDI engines in the European market started towards the end of 1997, and other manufacturers have also produced GDI engine vehicles.

Reductions in CO_2/km based on the 1999 Mitsubishi Carisma (DETR, 1999) are 11%:

Carisma 1.6i 16v, fuel economy 5.6 l/100km, CO_2 emissions 170g/km
Carisma 1.8 GDI, fuel economy 5.1 l/100km, CO_2 emissions 152g/km

These CO_2 emission rates are the results of test required under EU Directive 93/116/EC for all new cars, and are for a combined test cycle (urban and extra urban/highway).

DISC Engine (Advanced GDI Engine)

The DISC (Direct Injection Stratified Charge) engine incorporates VVLT and Cylinder Deactivation into a lean burn GDI engine and is the next step further down the line from GDI technology engines. The charge stratification in the combustion chamber allows a range of fuel qualities to be used satisfactorily and, by the more complete combustion of an overall weak charge with excess air, good fuel consumption and low exhaust emissions can be achieved.

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[8] At the workshop held to discuss the draft of this chapter, there was considerable debate as to a representative value for difference in fuel efficiency between a diesel and petrol car. The value of 20% used in this study represents a mid range.

The DISC engine is approaching implementation in Japan and is expected to be fully implemented in Europe by 2005. The main problem at the moment is that DISC engines produce higher NO_x levels and require a de-NO_x catalyst, which is still being researched. Several companies have such engines at the experimental/prototype stage (Poulton, 1997), and implementation in Europe by some companies is expected by 2005. Uptake of DISC engines (and possibly GDI engines) is likely to require the availability and use of very low sulphur/sulphur free fuel, as this is likely to be needed for the de-NO_x catalyst to operate (see 3.4.1).

Average reductions in fuel consumption compared to an engine of similar performance restricted to stoichiometric operation have been reported at 25% (Bates, 1998), although others believe that actual improvements, (based on running on sulphur free fuel) will be about 15%[9]. A value of 20% is taken for this study.

Hybrid Power Train Vehicle

A hybrid vehicle combines a combustion engine with an energy storage device (i.e. Battery, Ultracapacitor or Flywheel). The combustion engine runs at its optimum efficiency continuously so that during periods of relatively low power demand it can be used to simultaneously propel the vehicle and charge the energy storage device. During periods of peak power demand, both the engine and the energy storage device can simultaneously provide energy. Another advantage of hybrid power trains is that the energy storage device can be used to recover energy during breaking. Urban drive cycle benefits are therefore higher relative to motorway driving due to the recaptured braking energy.

Various hybrid systems are possible and/or under development, including:

- Electric vehicles with a range extender – as described above a combustion engine (of reduced size) recharges the batteries during vehicle operation.
- Combustion engine vehicles with an electric auxiliary mode, which powers the car and very low speeds and during stop-start modes. This is the approach taken by PSA with the Citroen Xsara Dynalto.
- Parallel hybrid vehicles with a variable electric/thermal power ratio. An example of this is the Toyota Prius hybrid car, which has already been successful in Japan and the US, where it is available at a heavily subsidised price. Toyota and Honda are planning to launch hybrid vehicles commercially in Europe in 2000.
- Mitsubishi Motors Corp. has produced a diesel/accumulator hybrid system called MBECS-III, which recovers energy from braking as well as incorporating other fuel economy and emission reducing features. It is currently being used in the new model of the New Aerostar, a large commuter bus on sale in Japan since 1996.

Fuel Cell Electric Vehicles

If hydrogen ‘fuel’ and oxygen (from the air) are fed into a ‘fuel cell’, a voltage difference is produced which can be used to drive an electric current, which in turn can operate an electric motor. This can be used to power a fuel cell electric vehicle. There also exists the option of combining a battery system with a fuel cell to form a fuel cell-hybrid vehicle. More details on the fuel options available and potential CO_2 reductions possible for this option are given in Section 3.6.

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[9] Value provided by a reviewer.

3.2.1.3 Weight Reduction

Weight reduction improves fuel economy. Without adjustments for constant performance, a weight reduction of 10% provides a fuel economy benefit of about 5%. Re-sizing the engine for constant acceleration performance, the fuel economy benefit increases to about 8% for a conventional petroleum fuelled vehicle.

Options for further reductions in weight include (Austin *et al*, 1999):

- *Lightweight interior components:* Weight reduction of interior components using either fewer or lighter materials can give reductions of 1.2% CO_2/km.
- *High strength steel body:* Using high strength steel for the bodies reduces the overall mass of metal needed to achieve the same performance levels, reducing the overall vehicle mass, and CO_2 per km by 3.0%.
- *Lightweight chassis, aluminium engine block and body:* Lighter weight chassis, engine blocks and bodies allow for smaller engines and consequently smaller transmissions. Overall reductions in CO_2 per km are 3.1%, 1.2% and 6.4% respectively.

All weight reductions would in turn allow for lighter suspensions and brakes, which could reduce the vehicle weight and consequently CO_2 emissions further.

Several companies are examining the use of aluminium instead of steel in car bodies to reduce car weight. Audi are launching a high volume, all aluminium car which has a body that is 40% (150kg) lighter than a conventional body and Ford also has several prototypes of aluminium based cars. Opel's G90 concept car has a total weight of only 750 kg due to its comprehensive lightweight construction and targeted use of aluminium and magnesium.

3.2.1.4 Friction and Drag Reduction

Engine Friction Reduction

Improved lubrication of engine parts leads to reduced loss of energy to friction within the engine, and hence improved efficiency. Information from vehicle manufacturers indicates significant changes in the types of lubricants being used, and increased efficiency will be achieved with oil, water and/or fuel pumps. Most of the techniques to reduce engine friction are already incorporated into current vehicles and a further improvement of only 0.5% CO_2/km is foreseen in the near future.

Aerodynamic Drag Reduction

Reducing the drag on a vehicle by improving the aerodynamics also reduces the power required to achieve the same performance, improving fuel efficiency and reducing the CO_2 emissions. Reductions in drag have been continuously occurring for many years and the estimated future reductions are not large; reductions of only 0.5% CO_2/km are expected.

Rolling Resistance Reduction

Use of tyres with a lower rolling resistance reduces the drag on a vehicle. Revised tread compounds, tread patterns and basic structural changes should allow further improvements to fuel economy in the future, although safety considerations may limit the maximum reduction which can be implemented. An estimated 5% decrease in tyre rolling resistance by 2005, is thought to be feasible, leading to a reduction in CO_2/km of 0.9% (Austin *et al*, 1999). Greater reductions have been reported by some, for example 'Pax System' tyre developed by Michelin (Michelin, 2000) which has shorter sidewalls, is claimed to have a rolling resistance which is 10%. However others believe that only an additional 5% improvement might be achieved in the future (compared to the state of the art low resistance tyres available today). An improvement of 5% leading to a reduction of 0.9% in CO_2/km is used in this study.

Theoretically, it is possible that redesigning road surfaces to produce a smoother surface could reduce rolling resistance. However, a certain 'roughness is required for safety reasons, to reduce the likelihood of skidding particularly in wet weather. This option is therefore not considered feasible at the present time[10].

Zero Brake Drag

Reducing brake drag requires modifying the design of brake systems so that any contact between the brake pads/shoes and the braking surface (disks or drums) is avoided until the brakes are applied. Success in this area reportedly achieved by BMW has led to the conclusion that brake drag could be essentially eliminated (Austin *et al,* 1999), leading to a reduction in CO_2/km of 1.1%[11].

3.2.1.5 Reducing N_2O emissions from Vehicles equipped with Catalysts

As discussed in Section 2.1, emissions measurements on petrol cars equipped with 'first generation' three way catalysts showed a substantial (ten-fold) increase in N_2O emissions compared to vehicles without catalysts, but it now seems likely that the increase in emissions from more modern catalysts is substantially less than this.

It appears that N_2O emissions are mostly formed during the 'light-off' phase, when the catalyst is warming up, with peak concentrations of about 10% of the NO_x emitted by the engine. If the catalyst degrades as it ages, then the length of the light-off phase can be extended, and the period over which N_2O is emitted is extended and the catalyst ages and degrades. The length of the light-off phase and deterioration with age also affect the performance of the catalyst in reducing emissions of the pollutants it is designed to treat (NO_x, CO and NMVOCs) and recent developments in catalyst technology aim to tackle both of these problems. The solution is to ensure the catalyst comes up to temperature as quickly as possible after the engine starts up, and to make the catalysts extremely resistant to thermal degradation. Indeed modern catalysts exhibit much better thermal stability, and even after ageing there is typically very little difference in the light off profile between fresh and aged catalysts.

Indeed ensuring very rapid catalyst light-off is likely to be necessary to ensure that EU Stage III and IV limit values are met (in 2001 and 2006 respectively). The practice of locating the catalysts in Euro IV vehicles close to the engine rather than in an underfloor position helps to ensure a much steeper temperature ramp-up, and manufacturers report that the light off time can be reduced by about half (to about 30 seconds) compared to vehicles meeting Stage I/II limit values.

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[10] An option to reduce CO_2 emissions associated with the development of roads is to reduce the temperature at which asphalt is produced and layed using e.g. special binders, additives and new mixing techniques such as two phase mixing.

[11] A reviewer pointed out that for some vehicles currently on the market, brake drag is not measurable and the 1.1% reduction is therefore not applicable to the entire vehicle fleet.

The IPCC which recommends emission factors for estimating N_2O emissions from vehicles, has yet to revise its estimate for European vehicles with catalysts (of 0.05 g/km), although it does seem likely that this value is probably too high for more modern catalysts and almost certainly too high for vehicles meeting future Euro IV standards. In the US, a study by the USEPA (EPA, 1998) based on measurements from 23 cars, suggested a value of 0.0288 g/km for 'Tier 1' vehicles, which has led the IPCC to revise its recommended value for such US vehicles (IPCC, 2000). Measurements by Ford (Becker et al, 1999) of emissions from 13 prototype and production US cars and 9 trucks, found even lower emissions - an average of .011 g/km for cars and .015 g/km for trucks. These values were consistent with a value derived from measurements in a tunnel in Germany, which found emissions of N_2O were 0.00006 g per g of CO_2. For vehicles with a fuel consumption of between 6-12 l per 100 km, gives N_2O emissions of 0.008 to 0.016 gN_2O/km. While a direct comparison between US and European cars is difficult, both because of differences in drive/test cycles and in the emission standards the cars are designed to meet, it seems likely that a Tier 1 US vehicle is equivalent to something between a Euro II and Euro III vehicle. Overall therefore it seems likely that a more realistic estimate e of elisions from cars with modern catalyses might be about half the value currently suggested by the IPCC for European vehicles (0.05 g/km). For the purposes of projecting N_2O emissions for this study, the value for US Tier 1 vehicles of 0.0288 g/km is used (Section 4.4). This is an area where further work to produce quantitative, reviewed data on N_2O emissions from European vehicles with new catalysts is needed.

3.2.2 Cost of Options

Sources and assumptions for the cost of options are summarised below. Many of the costs are drawn from work carried out for the Canadian National Climate Change Process – Transportation Table Subgroup by Austin *et al* (1999) in the US. A drawback of this data set is that there are some differences between the Canadian and US vehicles for which the data was originally derived and European vehicles, but wherever possible, data have been adjusted to reflect European conditions and practices. Advantages of the data set is that it is comprehensive, detailed, cohesive and up to date. All costs have been converted to $€_{1990}$, using a methodology and currency conversion rates and 'deflators' defined for the study as a whole. In general terms the cost-effectiveness of the measure is calculated by annualising the capital cost of the measure and annual savings (from improvements in fuel economy) and any additional annual costs (e.g. from additional maintenance) to calculate an annualised cost for the measure. The annualised cost is then divided by annual reduction in greenhouse gas emissions to give the cost-effectiveness in €/t CO_2-eq. A discount rate of 4% (as used through out the whole study) is used to calculate the annualised cost.

Two estimates have been made of the cost-effectiveness of each of the measures:

- Cost-effectiveness as perceived by the consumer: this is based on 'pump prices' for fuels i.e. fuel prices which include excise duty and any other taxes, and sale prices for vehicles (i.e. including any sales or other taxes levied at point of purchase)
- Cost-effectiveness based on 'production' costs: this is based on fuel and vehicle prices without taxes. As excise duty on transport fuels is high in most countries, accounting for up to 70% of fuel price in countries such as the UK, exclusion of taxes has a significant impact on the estimate of cost-effectiveness.

Taxes on both vehicles and fuels vary significantly thought the EU, and in order to present a 'typical' weighted average of tax levels were calculated based on tax levels in individual Member States and fuel consumption and number of vehicles in Member States.

The general assumptions made in calculating fuel economy and costs are:

- Constant performance (i.e. the engine is resized where measures change its performance)
- No impact on other attributes (e.g. drivability and noise, vibration and harshness) caused by the measure.
- All calculations are for mid-size automatic gearbox Sedans, which would be comparable to medium to large sized European saloon cars.
- Fuel economy is calculated using assuming a urban:highway travel ratio of 55%:45%.
- Weight reductions are based on the most optimistic estimates obtained from any one manufacturer in each area.
- Costs are estimated for measures implemented in 2005.
- The capital cost of measures in the Canadian study is a 'retail price estimate' which is based on manufacturing costs, 20% manufacturing mark up and a 12% dealer mark up. This has been taken as the 'production cost'; cost to consumers was estimated by adding on appropriate tax levels in Member States.

Assumptions specific to the individual measure are summarised as follows:

CVT: Automatic transmission cars are not common in Europe and the impact on more efficient European manual gearboxes has been estimated by halving the percentage fuel economy improvement estimated by Austin *et al* (1999). An additional cost of € 1227 added for the cost of conversion to an automatic gearbox. This figure was obtained from the difference between a manual and automatic VW Golf (Volkswagen AG, 2000).

Petrol-Diesel Shift: An examination of retail prices for several manufacturers were examined showed that the difference in current prices of similar specification petrol and diesel versions of cars varied considerably. As the basis for this variation could not be identified, an estimate of the price differential (exclusive of tax) between a diesel and petrol engine was taken from Teotia *et al* (1999). This estimate the difference as 744 $€_{1990}$ in 2000, falling to 559 $€_{1990}$ in 2010. The price for 2000 is used.

GDI Engine: Costs (£500 = € 740, 1999) and reductions in CO_2 per km (11%) are based on the 1999 Mitsubishi Carisma (Mitsubishi Motors, 2000):

Carisma 1.6i 16v, £13795, fuel economy 5.6 l/100km, CO_2 emissions 170g/km
Carisma 1.8 GDI, £14295, fuel economy 5.1 l/100km, CO_2 emissions 152g/km

DISC Engine: An American study estimates the increased cost of the DISC engine to be up to US$850 (OTA, 1995), and the de-NO_x catalysts (as also needed by diesel vehicles) are estimated to add € 125 to the year 2000 price, giving a total cost of 788 $€_{1990}$.

Hybrid Vehicle: Estimates of the 2005 costs of Hybrid power train technology has been estimated for three possible types of storage devices by OTA (1995):

Battery - US$4420 Ultracapacitor - US$9730 Flywheel - US$7260

The mean value of the three costs of 5677 $€_{1990}$ has been used as an estimate of the average cost of the measure.

Weight Reduction: Costs were calculated from Austin *et al* (1999) using a scaling factor of 0.8, to reflect the fact that European vehicles are generally smaller than those in the US.

Aerodynamic Drag Reduction: Costs were calculated by Austin *et al* (1999) using a drag coefficient (C_d) for passenger cars of 0.28.

Additional assumptions made for calculating annual savings and annual CO_2 savings are:

- CO_2 emission factors for one of the most common sizes of vehicle of 182 g CO_2/km and 135 g CO_2/km for petrol and diesel respectively (DETR, 1999).
- A weighted average (for the EU) fuel cost excluding excise duty and other taxes of $€_{1990}$ 0.162 per litre of petroleum and $€_{1990}$ 0.172 per litre of diesel (derived from PRIMES)[12].
- A weighted average (for the EU) annual distance travelled per car of 13,679 km (derived from PRIMES).

All costs have been converted to 1990 €; annualised costs have been calculated at a 4% discount rate, in line with the rest of the study. Table 3.1 and Table 3.2 show the cost-effectiveness of measures for petrol and diesel cars based on costs incurred by consumers (i.e. including fuel and sales taxes). Table 3.3 and Table 3.4 show the cost-effectiveness of the measures excluding taxes.

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[12] Only 'average' EU figures are shown in the following tables, but calculations at the Member State level were also made, bases on tax levels, average annual mileages etc in individual Member States.

Table 3.1 Cost-Effectiveness Analysis for Technical Measures to Reduce CO_2 Emissions from Petrol Cars (Including Taxes)

Measure	% Reduction in CO_2 per km	Capital Cost, €	Annual Saving, €/yr	Lifetime (years)	Annualised Cost at 4% DR (€/yr)	Emissions Reductions (t/yr)	Cost-Effectiveness (€/t CO_2)
Engine Efficiency Improvements							
Hi-Speed Engine with Variable Valve Lift & Timing	6.9%	412	-57	12	-13	0.172	-76
Cylinder Deactivation at Idle and Part Load	11.3%	250	-94	12	-67	0.282	-238
CVT (Continuously Variable Transmission)	5.1%	1431	-42	12	110	0.128	863
Major Engine Changes							
Petrol to Diesel shift	20.0%	940	-165	12	-65	0.498	-131
Hybrid Power Train Vehicle	32.8%	7176	-271	12	494	0.816	604
GDI Engine	11.0%	709	-91	12	-15	0.274	-56
DISC Engine	20.0%	996	-165	12	-59	0.498	-119
Weight Reduction							
Lightweight Interior Components	1.2%	29	-10	12	-6.70	0.030	-227
High strength steel body	2.4%	85	-20	12	-11	0.060	-181
Aluminium Body	6.4%	536	-53	12	4	0.160	24
Lightweight Chassis	3.1%	269	-26	12	3	0.077	40
Aluminium Block	1.2%	99	-10	12	1	0.030	24
Friction and Drag Reduction							
Engine friction reduction	0.5%	17	-4	12	-2.3	0.012	-185
Aerodynamic Drag reduction	0.5%	30	-4	12	-1	0.012	-73
Rolling resistance reduction	0.9%	27	-7	3	2.4	0.022	109
Zero Brake Drag	1.1%	85	-9	12	0	0.027	4

Table 3.2 Cost-Effectiveness Analysis for Technical Measures to Reduce CO_2 Emissions from Diesel Cars (Including Taxes)

Measure	% Reduction in CO_2 per km	Capital Cost, €	Annual Saving, €/yr	Lifetime (years)	Annualised Cost at 4% DR (€/yr)	Emissions Reductions (t/yr)	Cost-Effectiveness (€/t CO_2)
Engine Improvements							
CVT (Continuously Variable Transmission)	5.1%	1431	-22.5	12	130	0.095	1373
Major Engine Changes							
Hybrid Power Train Vehicle	32.8%	7176	-144.0	12	621	0.606	1025
Weight Reduction							
Lightweight Interior Components	1.2%	29	-5.2	12	-2	0.022	-96
High strength steel body	2.4%	85	-10.6	12	-2	0.045	-34
Aluminium Body	6.4%	536	-28.3	12	29	0.119	242
Lightweight Chassis	3.1%	269	-13.6	12	15	0.057	264
Aluminium Block	1.2%	99	-5.2	12	5	0.022	242
Friction and Drag Reduction							
Engine friction reduction	0.5%	17	-2.2	12	0	0.009	-39
Aerodynamic Drag reduction	0.5%	30	-2.2	12	1	0.009	112
Rolling resistance reduction (5%)	0.9%	27	-3.9	3	6	0.016	356
Zero Brake Drag	1.1%	85	-4.8	12	4	0.020	216

Table 3.3 Cost-Effectiveness Analysis for Technical Measures to Reduce CO_2 Emissions from Petrol Cars (Excluding Taxes)

Measure	% Reduction in CO_2 per km	Capital Cost, €	Annual Saving, €/yr	Lifetime (years)	Annualised Cost at 4% DR (€/yr)	Emissions Reductions (t/yr)	Cost-Effectiveness (€/t CO_2)
Engine Efficiency Improvements							
Hi-Speed Engine with Variable Valve Lift & Timing	6.9%	326	-13	12	22	0.172	127
Cylinder Deactivation at Idle and Part Load	11.3%	198	-21	12	0	0.282	-1
CVT (Continuously Variable Transmission)	5.1%	1132	-10	12	111	0.128	870
Major Engine Changes							
Petrol to Diesel shift	20.0%	744	-38	12	42	0.498	84
Hybrid Power Train Vehicle	32.8%	5677	-62	12	543	0.816	665
GDI Engine	11.0%	561	-21	12	39	0.274	143
DISC Engine	20.0%	788	-38	12	46	0.498	93
Weight Reduction							
Lightweight Interior Components	1.2%	23	-2	12	0.23	0.030	8
High strength steel body	2.4%	67	-5	12	3	0.060	44
Aluminium Body	6.4%	424	-12	12	33	0.160	206
Lightweight Chassis	3.1%	213	-6	12	17	0.077	219
Aluminium Block	1.2%	78	-2	12	6	0.030	206
Friction and Drag Reduction							
Engine friction reduction	0.5%	14	-1	12	0.5	0.012	41
Aerodynamic Drag reduction	0.5%	24	-1	12	2	0.012	130
Rolling resistance reduction	0.9%	21	-2	3	6.1	0.022	273
Zero Brake Drag	1.1%	68	-2	12	5	0.027	190

Table 3.4 Cost-Effectiveness Analysis for Technical Measures to Reduce CO_2 Emissions from Diesel Cars (Excluding Taxes)

Measure	% Reduction in CO_2 per km	Capital Cost, €	Annual Saving €/yr	Lifetime (years)	Annualised Cost at 4% DR (€/yr)	Emissions Reductions (t/yr)	Cost-Effectiveness (€/t CO_2)
Engine Improvements							
CVT (Continuously Variable Transmission)	5.1%	1132	-6.8	12	114	0.095	1203
Major Engine Changes							
Hybrid Power Train Vehicle	32.8%	5677	-43.3	12	562	0.606	927
Weight Reduction							
Lightweight Interior Components	1.2%	23	-1.6	12	1	0.022	41
High strength steel body	2.4%	67	-3.2	12	4	0.045	89
Aluminium Body	6.4%	424	-8.5	12	37	0.119	308
Lightweight Chassis	3.1%	213	-4.1	12	19	0.057	325
Aluminium Block	1.2%	78	-1.6	12	7	0.022	308
Friction and Drag Reduction							
Engine friction reduction	0.5%	14	-0.7	12	1	0.009	85
Aerodynamic Drag reduction	0.5%	24	-0.7	12	2	0.009	205
Rolling resistance reduction (5%)	0.9%	21	-1.2	3	7	0.016	398
Zero Brake Drag	1.1%	68	-1.4	12	6	0.020	287

3.3 NON-TECHNICAL MEASURES

3.3.1 Description of Options

‘Non-technical’ transport measures are typically classified according to their primary effects into three top-level categories:

- **operational** measures, affecting the amount of pollutants emitted per vehicle-km;
- **strategic** measures, affecting the vehicle-kilometres driven per unit of demand (expressed in passenger-kilometres/tonne-kilometres);
- **demand** measures, directly affecting the demand for travel (expressed in passenger-kilometres/tonne-kilometres).

Typical examples of operational measures are driver training schemes and (variable) speed limits. Strategic measures include car pooling, measures to encourage shift from private car use to more sustainable modes of transport (through e.g. reduced fares, improved information), and improving freight logistics to ensure vehicles travel less kilometres empty. Finally, demand type measures include options such as land use planning and travel substitution (e.g. teleworking). It is important to note that these measures are actual *solutions* to transport problems that can be implemented by local authorities and national governments. Various *policy levers* and *instruments* can act upon the *solutions* to encourage or force people to make use of these. Policy levers include information and awareness initiatives as well as pricing and regulatory measures, which are designed to encourage the adoption of technical measures such as scrappage subsidies, graduated vehicle tax and tax differentials between petrol and diesel. Comprehensive lists of measures (*solutions* and *policy levers*) relevant to fuel efficiency and CO_2 emissions are shown in Appendix 3. These lists represent the range of measures one could theoretically look at. At present there is little quantitative and transferable data on the effectiveness and costs of many of these measures. In the longer term these types of measures, which are geared at changing the behaviour of transport users, could be key in tackling emissions from transport.

A comprehensive ongoing review of non technical measures for reducing CO_2 and other air pollutants is being undertaken in the Commission’s CANTIQUE project (Concerted Action on Non-Technical Measures and their Impact on Air Quality and Emissions). To date the project team has found that:

- The actual impacts of non technical measures on reducing emissions are unevenly documented.
- Costs of measures are available in under half of the investigated 24 studies.

A summary on the impact of non-technical measures produced by the CANTIQUE project, drawn from 24 studies across Europe, and including the AutoOil II programme is shown in Table 3.5. In many cases, data is only available on the impact on primary traffic indicators such as vehicle kilometres or traffic volume rather then CO_2 emissions.

Where data on cost and cost-effectiveness is available, it is not available on a consistent basis, and the CANTIQUE project is currently developing a methodology to produce ‘best’ estimates of the costs of the most effective measures. The other problems in estimating the impact of these measures in an EU wide situation is that many measures are applicable to only a particular type of area (e.g. large urban areas) and, even within such an area, impacts can vary significantly from city to city, depending on specific local circumstances. Given these challenges, a first attempt at estimating the impact in an EU wide situation with the MURE model concluded that:

- The effectiveness of measures across Europe has a strong relationship with country-specific transport indicators such as specific energy consumption, average distance travelled and stock vehicle characteristics.
- The variability of effectiveness of measures within countries depends on the presence of contrary or complementary effects - the more the implementation of a measure involves trade-off evaluation, the more the expected effectiveness varies in terms of emissions savings.

Under the Auto Oil II programme, the impact of non-technical measures on transport demand and emissions has also been examined using the TREMOVE model. Although the primary aim of the assessment was to examine the effectiveness of measures in reducing emissions of pollutants contributing to poor urban air quality, their impact on CO_2 emissions was also examined, and results are shown in Table 3.6. The reduction in emissions and costs refer to the geographical areas specified in the table. The range of costs included in the assessment is much broader than those included in the assessment of technical measures in this study and are therefore not directly comparable. They include

- Costs borne by the users of the transport system (monetary and time costs).
- Costs for investment, administration, operation and maintenance, borne by the institutions responsible for the implementation of the measures, including governments at local and national level (including the net effect of any changes in tax revenues), EU funds, transport operators, industry.
- Additional costs to the society in form of external effects such as CO_2 emissions, noise, and accidents.

The negative net present value (NPV) for many of the measures indicates a net benefit to society and the results of the modelling (and of other case studies reviewed by the Auto Oil II programme) do indicate a substantial no regret (or win-win) potential. That is, there a number of non-technical measures which can reduce road transport emissions (of both urban air pollutants and CO_2) and have a net benefit to society by making transport more efficient and reducing congestion. As in the CANTIQUE programme the Auto Oil report concluded that there is a need to improve knowledge of the impacts and costs of non-technical measures.

Table 3.5 Impact Of Non-Technical Measures

STAND ALONE MEASURE	CO_2	Vehicle km	Traffic volume	Average Speed	Fuel Consumption	Projects or Studies and Location	**PACKAGES OF MEASURES**	CO_2	Vehicle km	Traffic volume	Fuel Consumption	
Park & Ride	-2%	-1%				LfU (German cities < 20.000 inhabitants)	- Park & Ride & Bus-shuttle lines			-6% (cars)		AIUTO (Salerno)
Car Pooling		*-31%*				START (Italian urban areas)						
Dial-A-Ride					-.1%	AIUTO (Como)						
Road pricing	 -7% -21% - 8.7% - 7.9% - 9.8% - 12.3% - 9.7%	-8% -5% -22% - 9.6% - 11.6% - 8.8%	 -4,3% -7% -6%	 + 2.7% + 3.6%	-13%	AIUTO (Como) START (London – inner -) START (Italian urban areas) START (London) TRANSPRICE (Athens) AUTO OIL II (Athens) AUTO OIL II (Lyon) EUROTOLL (Stuttgart) EUROTOLL (Stuttgart) EUROTOLL (Stuttgart) GAUDI (Trondheim)	- Road pricing & New Tunnel	-4,7%			-1,6%	AIUTO (Thessaloniki)
Parking pricing	 - 13.2% - 11.1%	-4% -1,2% 0,1% -1,9%		 + 3.1% + 3.4%	-6,3%	AIUTO (Como) SPARTACUS (Helsinki) SPARTACUS (Bilbao) SPARTACUS (Naples) AUTO OIL II (Athens) AUTO OIL II (Lyon)	- Park pricing & Dial-a-Ride - Park pricing & Car Pool - Park pricing & PT Increase - Park pricing & Management Measures		 -5% -5% -6% -3% (cars)		-0,13% -8,3% -9,2%	AIUTO (Como) AIUTO (Como) AIUTO (Como) AIUTO (Salerno)
PT fare structure	 - 1.2%	-13%	 -1% (cars)	 + .3%	-18,9%	AIUTO (Como) START (Basque Country) AUTO OIL II (Athens) AIUTO (Salerno) COST CITAIR 616						

STAND ALONE MEASURE	CO_2	Vehicle km	Traffic volume	Average Speed	Fuel Consumption	Projects or Studies and Location	**PACKAGES OF MEASURES**	CO_2	Vehicle km	Traffic volume	Fuel Consumption	
Access control & limitation (speed limit)	-3%	-4,6% -1,3% -1,3%	-33/78%			MASTER(Hungary) ERTICO ITS (Barcelona) SPARTACUS (Helsinki) SPARTACUS (Bilbao) SPARTACUS (Naples) LfU (Stuttgart) PISHINGER e al. (Graz) F.E.A (Germany)	- Access central area limitation & Park pricing - Traffic calming & New Tunnel - Access control residents/visitors & Park pricing	-4,7%		-12% (cars) -20%	-1,6%	AIUTO (Salerno) AIUTO (Thessaloniki) TRANSPRICE (Como)
Parking management			-15% -.7% (car) -5%		-2,1%	LfU (Stuttgart) ERTICO ITS START M.HERRY, *et al*Vienna	- Parking control & Access limitation			-30% (veh.day)		CAPTURE (Rome)
Pedestrian and cycling					-14%	INESTENE (Strasbourg)	- Pedestrianisation & New Tunnel arterial - Pedestrianisation & New Tunnel arterial, PT bus lanes & traffic calming & parking management - Pedestrianisation & New Tunnel arterial & Metro - Pedestrianisation & New Tunnel arterial & Metro & PT bus lanes & traffic calming - Pedestrianisation & New Tunnel arterial & Metro & PT bus lanes, traffic calming & parking management	-4,7% -4,7% -4,9% -4,9% -4,8%			-1,6% -1,6% -1,8% -1,8% -1,8%	AIUTO (Thessaloniki) AIUTO (Thessaloniki) AIUTO (Thessaloniki) AIUTO (Thessaloniki) AIUTO (Thessaloniki)

STAND ALONE MEASURE	CO_2	Vehicle km	Traffic volume	Average Speed	Fuel Consumption	Projects or Studies and Location	**PACKAGES OF MEASURES**	CO_2	Vehicle km	Traffic volume	Fuel Consumption	
PT measures 1)Bus Priority 2)Increased frequency	- .3%	-1%		- .9% +3% -10%	-7% -7% - .8%	AUTO OIL II (Athens) QUARTET PLUS (Athens) INESTENE (France) ERTICO (Turin) ERTICO ERTICO ITS (Gothenburg) AIUTO (Como)	- Promote Public Urban Transports & Land Use Policies -Promote Public Urban Transports & Infrastructure measures - Infrastructure measures (New metro line)	+0,1%	-9% -3,2% -4%	-9,5% -8,2% (cars) -5% -9% +1%	-4,1% g/veh*km -8% +0,1%	ESTEEM (Lyon) ESTEEM (Brussels) ESTEEM (Rome))
ITS/UTC measures (traffic lights)	-0,2			+1,1%	-2/3% -14%	AUTO OIL II (Athens) OPTIONS TO REDUCE NO_X AND…(Glasgow) INESTENE (France urban area) TRANSYT (Larisa – Greece)	PTS (Public Transport System) ITC & PTS (Pre-trip travel information, etc) UTC & Public Transport Facilities Traffic optimisation and reduction	-2,2% -5,3% -20%	-1,7% -3.5%	-1,3% -4,5%	-2,2% - 8% -20%	QUARTET PLUS II (Gothenburg) QUARTET PLUS II (Stuttgart) QUARTET PLUS II (Turin) GERMAN AUTOMOBILE INDUSTRY (VDA), Koln
Ramp metering				+20%		ERTICO ITS						
Staggered activity time				+ 4,5%		AIUTO (Geneva)						
Taxes (on fuel, vehicle scrappage)	+.4%	-15,5% -7,8% -14,6% -2% -4% -6%	-5% (cars)	-.1%	-8,5%	SPARTACUS (Helsinki) SPARTACUS (Bilbao) SPARTACUS (Naples) *DESGUPTA e al. (UK)* *HELVI (Finland)* AUTO OIL II (Athens) AIUTO (Como) AIUTO (Salerno)	Financial Incentives & awareness campaigns Financial incentives and awareness campaigns and car cost increase	-4% -2.1%	+.3% -2.3%			EFFECTIVENESS OF ALTERNATIVES (West Germany) EFFECTIVENESS OF ALTERNATIVES (West Germany)
Fleet & freight management -City Logistics	2.5%	-10%	-6% (freight) +1%	+ .7%	-3% -1% -4/5% -3% -3%	COST 321 (European average) AUTO OIL II (Athens) COST 321 (European average) METAFORA COST 321 (European average) COST 321 (European average)	Implementation of Freight Platform and ban on heavy trucks Alternative Freight Distribution	-15% (trucks)	+2.9% -1.3% (trips)		+6.2%	REFORM (Brussels) REFORM (Rome)
Tele-working		-0,9% -2,0%	+5%	+5%		SPARTACUS (Helsinki) SPARTACUS (Bilbao) SPARTACUS (Naples)						
Information to users	-7%		+3%		-3% -10% -5/10%	PROGNOS *et al* (Germany) OECD (the Netherlands)						

STAND ALONE MEASURE	CO_2	Vehicle km	Traffic volume	Average Speed	Fuel Consumption	Projects or Studies and Location	**PACKAGES OF MEASURES**	CO_2	Vehicle km	Traffic volume	Fuel Consumption	
Regulation enforcement							- Regulatory Measure & Internalisation of external costs (Scenario R)	-1,4%	-1,2%			EFFECTIVENESS OF ALTERNATIVES…. (West Germany)
							-Zoning- restricted access &Traffic Reduction Act	-8,4%			-7,2%	ESTEEM (London)
							-Restrictive traffic rules for heavy vehicles				+2,1%	REFORM (Brussels)

Source:CANTIQUE, 2000

2) i.e. with increase of bus frequency only during peak.
3) Costs and budget impact for Greece, relative emission impact for Athens.
Source:Auto Oil II Programme, November 1999.

Table 3.6 Social costs and main emission impacts of non-technical measures (Auto Oil II)

Measure	Area	Social costs (NPV in mio. ECU)		Emission impact (2010)		
		NPV1[1]	NPV2[1]	CO_2	NOx	PM
Road capacity +5%	Athens	-1720	-1682	-0.1%	0.0 %	-0.8 %
Bus prioritisation	Athens	718	664	-0.3%	-0.6 %	-0.4 %
Public transport fare -30%	Athens	-1049	-1143	-1.1%	+0.4 %	+1.6 %
City logistics (load +10%)	Athens	-8931	-9320	-2.6%	-2.8 %	-5.7 %
Parking charge (3 ECU)	Athens	-868	-1818	-12.9%	-5.7 %	+1.4 %
Parking charge (3 ECU)	Lyon	-1245	-1488	-10.8%	-2.1 %	-8.7 %
Time-differentiated road pricing	Athens	-649	-1168	-8.5%	-5.5 %	-3.8 %
	Lyon	-1252	-1399	-7.7%	-2.9 %	-6.2 %
Scrappage scheme	Greece[3]	533	571	+0.3%	+0.1 %	0.0 %

1) Net present value excluding (NPV1) and including (NPV2) noise and accident costs.

3.4 OTHER TRENDS IN PASSENGER CAR CO_2 EMISSIONS

There are a number of other trends in passenger car design which might be expected to have an impact on CO_2 emissions, and which it was not possible to take into account in the analysis carried out for this report. These are discussed below.

3.4.1 Impact of New de-NO_x and Particulate Catalysts

Tailpipe emissions of NO_x and (for diesel) particulate emissions will need to be reduced under EURO IV standards due to be introduced in 2006. One new particulate filter that has been developed has been shown in early tests to increase CO_2 emissions by 5%, although manufacturers expect to be able to reduce this to a 2 to 3% penalty. The de-NO_x catalyst that will be required could be expected to have a CO_2 penalty of the same order of magnitude. (The impact of new catalyst technology on N_2O emissions is considered in Section 3.2.1.5 and Section 4.4.) De-NO_x techniques/catalysts may require a very low sulphur content fuel which could have implications in the refinery sector (see below).

3.4.2 New Fuel Specifications

Some of the current changes in fuel specification being considered (e.g. lower sulphur and benzene contents) could have implications for the refining process and lead to increased energy use and hence CO_2 emissions in the refineries sector. For example, increased processing of refined products may be likely. Future specifications for fuels are likely to lead to more severe modifications for diesel fuel than petrol.

3.4.3 Increased Consumption by Accessories

There is a continuing trend for consumers to demand increased ‘comfort’ levels in vehicles, e.g. electric windows, air conditioning, entertainment systems, and these accessories, particularly air conditioning can significantly increase fuel consumption[13]. For example, one study by ADEME found that the use of air conditioning can lead to an increase of 10 to 15 % in fuel consumption, depending on engine type and climatic conditions etc. (Gauducheau, 2000). In the warmer southern European Countries,

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[13] It should be noted that the measurements for the ACEA agreement to reduce CO2 emissions are based on a test cycle where no accessories are operational.

this could have a significant impact on CO_2 emissions from vehicles, e.g. 60% of new cars sold in France have air conditioning. Possible ways of tackling this potential increase are designing accessories to minimise energy consumption and using 42V technology.

3.4.4 Safety Requirements

The weight of cars has begun to stabilise or decrease, but it is possible that any new safety requirements that are introduced might reverse this trend.

3.4.5 Changes in the Vehicle Fleet

Any changes in the type of car purchased could influence overall CO_2 emissions. For example, increased numbers of large four wheel drive type vehicles would increase total emissions from the vehicle fleet.

3.5 OPTIONS FOR FREIGHT

3.5.1 Description of Options

3.5.1.1 Engine Improvements

Possible improvements include:

a) Reducing engine friction and parasitic losses (small contribution for heavy vehicles).
b) Reducing heat loss to coolant.
c) Recapturing and using exhaust heat energy.

Options b) and c) can be achieved by using adiabatic turbo-compound diesel engines combined with heat conservation. The basic concept is to insulate the combustion chamber and exhaust passages and then recover exhaust heat energy with a turbine geared to the output shaft. This has been researched for more than 30 years and has a possible market penetration at 10% by 2010 (Austin *et al* (1999).

Engine improvements could reduce CO_2 per km by 5.7%.

3.5.1.2 Weight Reduction

The potential for reducing fuel consumption for heavy-duty vehicles by reducing their weight is very limited as:

- The cargo load is a high fraction of total loaded vehicle weight.
- Maximum limits on gross vehicle weight have already provided economic incentives for vehicle weight reduction.

A reduction of 0.4% in CO_2/km is estimated to be achievable.

3.5.1.3 Aerodynamic Drag Reduction

Heavy-duty trucks have significantly larger aerodynamic drag than passenger cars and light-duty trucks because of their relatively large cross-sectional area and their lack of streamlining. Two methods for reducing aerodynamic drag for articulated trucks, which have been identified (EEBPP, 2000) are:

a) *Cab roof fairing* - a three-dimensional moulding that fits onto the cab roof.
b) *Cab roof deflector* - essentially a flat or slightly contoured plate of variable angle supported on the cab roof.

These are estimated to reduce CO_2/km by 3.7% and 2.4% respectively.

3.5.1.4 Reduced Rolling Resistance

The use of lower profile, radial tyres on heavy-duty trucks has significantly reduced rolling resistance. Revised tread compounds, tread patterns and basic structural changes should allow further improvements to fuel economy by up to 3.8%.

3.5.1.5 Driver Training

Fuel efficiency can be influenced significantly by driving style. A one-day course can be run to train drivers to drive more economically, resulting in a 5% improvement in fuel economy. Studies show that the effectiveness of the training drops off with time, so it is best to be refreshed annually.

Estimated costs are €375 per day's training for two drivers, and an additional €120 cost for each agency driver required to cover for the permanent drivers whilst they are being trained. Total costs per driver are thus €307.5 per year.

3.5.1.6 Freight Logistics Optimisation

Better load management and route planning, can avoid unnecessary journeys and transport of half-empty loads. There is plenty of qualitative information available on reductions in kilometres travelled, but quantitative information is often only available on a local scale. As an example, one Dutch study estimated possible reductions achieved for eight different logistics (Table 3.7); as the measures partly overlap, the total reduction from introduction of all measures is expected to be a maximum of 15 - 20 % (IPM&ET, 1996). The cost-effectiveness of the measures was not estimated explicitly, but is expected in most cases to lead to costs savings.

Table 3.7 Vehicle Kilometre Reductions from Freight Logistics Measures

Logistics measure	*vkm reduction [% of total vkm]*	*total costs*
Vehicle size increase (up to 60 tonne HGVs)	6	negative
Better co-ordination between transport operators	5	negative
Reduced and standardised packaging materials	5	negative
Improved logistic organisation (fleet management, mobile communications, co-shippership)	4	negative
Contracting out to professional transport operators	3	may be positive
Full cabotage	2	negative
Improved route planning for large operators	2	negative
City distribution centres	1	positive

Source: IPM&ET, 1996

3.5.1.7 Intermodal Freight Transport

Intermodal freight transport, i.e. combining road freight with rail or shipping transport modes, has great potential to reduce overall emissions of the freight sector. This may require substantial investment, standardised infrastructure and loading units, as well as future ‘smart’ transfer technologies, and is seen a cost-effective option for the short-to-medium term.

A Dutch study modelled the emissions effects of intermodal transport on CO_2 emissions in 2010. The key results were:

- In 2010, switching freight from road to *combined road-shipping* is expected to reduce CO_2 emissions per TEUkm by 50% compared to current road freight transport (a TEU is a Twenty foot Equivalent Unit, a common freight container unit; e.g., a 40 foot container can carry up to 2 TEU of freight).
- Also in 2010, switching freight from road to *combined road-rail* is expected to reduce CO_2 emissions per TEUkm by 50% compared to current road freight transport TEU.
- Taking exploitation and infrastructure costs into account, the total costs for combined road-shipping over long distances are expected to be 50% lower than for road freight only; similarly, the total costs for combined road-rail over long distances are expected to be 15% lower.
- Both options are expected to be cost-effective over long distances (greater than 200 km for road-shipping, and greater than 500 km for road-rail freight transport) (IPM&ET, 1995, 1996).

There are major obstacles, however, to the widespread implementation of intermodal transport, in particular the flexibility, speed and frequency of road transport over short distances. To overcome these obstacles, and to stimulate intermodal transport, concrete measures are needed, e.g.: international standardisation of loading units and intermodal freight carriers, efficient and cost-effective operations, and the co-ordination of long-distance and short-distance freight transport.

3.5.1.8 *Freight Transport Telematics*

Transport telematics and/or electronic data transfer improves the efficiency of the freight transport system by speeding up different phases of the system and improving co-ordination between production and consumption. The main effects are increased average utilisation factors and reduced loaded as well as empty trips.

The FORWARD study estimated that average utilisation factors could be increased to 2.54 for national transport and 1.46 for international transport, hence reducing tonne kms by about 60% and 30%, respectively. Dutch national costs for this action are estimated at about 125 million € capital investment and 27 million €/year operating costs. Overall, the FORWARD study concludes that this option is the most cost-effective option available in the freight sector (FORWARD, 1996).

3.5.2 Cost of Options

The cost-effectiveness of measures is calculated in the same way as for options for passenger cars. Two estimates of the cost-effectiveness of measures are made:

- Cost-effectiveness as perceived by the consumer: this is based on ‘pump prices’ for fuels i.e. fuel prices which include excise duty and any other taxes, and sale prices for vehicles (i.e. including any sales or other taxes levied at point of purchase).

- Cost-effectiveness based on ‘production’ costs: this is based on fuel and vehicle prices without taxes. As excise duty on transport fuels is high in most countries, accounting for up to 70% of fuel price in countries such as the UK, exclusion of taxes has a significant impact on the estimate of cost-effectiveness.

One source of information on measures and their costs is work carried out for the Canadian National Climate Change Process – Transportation Table Subgroup by T.C. Austin *et al* (1999). Additional information was obtained from the UK Energy Efficiency Best Practice Programme (EEBPP) on aerodynamics and driver training. The measures are currently available except for reductions in rolling resistance and improvements in engine efficiency, which are expected by 2005.

Additional assumptions made for calculating annual savings and annual CO_2 savings are:

- CO_2 emission factor of 1286 g CO_2/km for diesel trucks (calculated from PRIMES baseline scenario)
- Fuel costs of 1990 € 0.172 per litre of diesel (PRIMES - average across EU excluding tax).
- Average annual distance travelled per vehicle of 49,861 km for trucks (derived from PRIMES).

Sufficiently detailed cost data were not available in the original studies dealing with freight logistics optimisation, use of telematics and inter-modal freight transport to estimate the cost-effectiveness of these options in this study.

Table 3.8 Cost-Effectiveness Analysis for Measures to Reduce Freight CO_2 Emissions (including taxes)

Measure	% Reduction in CO2 per km	Capital Cost, €	Annual Cost, €	Annual Saving, €	Net Annual Cost /Saving, €	Lifetime (years)	Annualised Cost at 4% DR (€/yr)	Emissions Reductions (t/yr)	Cost-Effectiveness (€/t CO_2)
Engine Improvements	5.7%	389	0	876	-876	15	-841	3.629	-232
Weight Reduction	0.4%	1667	0	57	-57	15	92.83	0.236	393
Aerodynamic Drag Reduction – Cab Roof Fairing	3.7%	711	0	573	-573	15	-509	2.372	-215
Aerodynamic Drag Reduction – Cab Roof Deflector	2.4%	533	0	372	-372	15	-324	1.539	-210
Rolling Resistance Reduction	3.8%	0	0	581	-581	3	-581.2	2.407	-241
Driver Training – HGV Drivers	5.0%	0	275	774	-500	15	-500	3.206	-156

Table 3.9 Cost-Effectiveness Analysis for Measures to Reduce Freight CO_2 Emissions (excluding taxes)

Measure	% Reduction in CO2 per km	Capital Cost, €	Annual Cost, €	Annual Saving, €	Net Annual Cost /Saving, €	Lifetime (years)	Annualised Cost at 4% DR (€/yr)	Emissions Reductions (t/yr)	Cost-Effectiveness (€/t CO_2)
Engine Improvements	5.7%	289	0	263	-263	15	-237	3.629	-65
Weight Reduction	0.4%	1239	0	17	-17	15	94.28	0.236	399
Aerodynamic Drag Reduction - Cab Roof Fairing	3.7%	528	0	172	-172	15	-125	2.372	-53
Aerodynamic Drag Reduction - Cab Roof Deflector	2.4%	396	0	112	-112	15	-76	1.539	-49
Rolling Resistance Reduction	3.8%	0	0	175	-175	3	-174.6	2.407	-73
Driver Training – HGV Drivers	5.0%	0	275	233	42	15	42	3.206	13

3.6 ALTERNATIVE FUELS

An ‘alternative fuel’ is defined as one which could be used to partially or fully replace conventional petrol and mineral diesel fuels and which also offers potential air quality or climate change benefits. The main alternative fuels/propulsion technologies currently being developed which offer CO_2 reductions are briefly described below.

3.6.1 Biofuels

Biofuels are considered to reduce CO_2 emissions on a life-cycle basis, since it is assumed that vehicle tailpipe CO_2 emission are captured by the growing biomass feedstock.

i) *Ethanol/Petroleum*:
There are a number of different blend ratios of petroleum with ethanol (also known as bio-ethanol) from different sources such as corn or cellulose (Austin *et al*, 1999). Life-cycle reductions of CO_2 (relative to petroleum) can be up to 60% depending on the percentage of ethanol in the fuel (Brand *et al,* 1997).

ii) *Methanol/Petroleum:*
Also known as bio-methanol, blends of petroleum with methanol may also be used as alternative fuels. Life-cycle reductions in CO_2 emissions (relative to petroleum) of up to 80% have been predicted by Brand *et al* (1997).

iii) *Bio-Diesel:*
Esterification is used to process rape seed into Rape-seed Methyl Ester (RME), also known as bio-diesel.

Capital costs are not much higher than for conventional fuel vehicles. Biofuel costs depend on the route for production of the fuel but range from 50% more than mineral diesel to more than double (ECOTEC, 1999). Over the longer term (2010 – 2020) bioethanol costs are expected to become more comparable to diesel.

3.6.2 Liquefied Petroleum Gas (LPG)

This is primarily propane. Reductions of CO_2 have been reported around 10% by Brand *et al* (1997) and 25% by Austin *et al* (1999) relative to petroleum.

Disadvantages are higher vehicle capital cost and a requirement for an adapted refuelling infrastructure. Penetration of niche markets is predicted by 2005-2010.

3.6.3 Compressed Natural Gas (CNG)

Similarly reductions in CO_2 emissions to LPG have been reported of around 10% by Brand *et al* (1997) and 25% by Austin *et al* (1999) relative to petroleum. However, in the current French NGV (Natural Gas Vehicle) programme, NGV buses have 28-62% worse fuel consumption than diesel buses under real-life driving conditions.

Again, disadvantages are higher vehicle capital cost and an adapted refuelling infrastructure would be required. Penetration of niche markets is predicted by 2005-2010.

3.6.4 Fuel Cell Electric Vehicles

In fuel cell vehicles energy stored in gaseous or liquid fuel is transformed into electricity by electrochemical oxidation, producing water and some heat at the same time. Potential fuels and technologies are:

- ***Methanol***: The methanol is produced initially from natural gas and is reformed to hydrogen on-board the vehicle.
- ***Hydrogen***: The hydrogen can be produced by the electrolysis of water or from natural gas.
- ***Petrol***: A petrol reformer or multi-fuel processor can produce hydrogen on-board the vehicle in a similar way as for methanol.

Reductions of up to 100% CO_2 emission reduction are possible at the tailpipe if hydrogen is the fuel (Brand *et al* 1997), but this does not take into account CO_2 from other parts of the hydrogen cycle. The life cycle or “well to wheel” emissions (i.e. including CO_2 emissions associated with the production of the fuel) estimated in a number of studies for various fuel cell types are shown in Table 3.10. (Differences between studies are likely to be due to differing assumptions about the efficiency of the fuel cell and reformer, and possible to differing assumptions about the fuel production stages. In the case of the Canadian study [4], they also appear to be due to assumptions about the size and type of vehicles). For a fuel efficient petrol car of today, life cycle emissions might be about 170 g CO_2 per km, so fuel cell vehicles could offer reductions of up to 50%, although with some technology/fuel combination, the reduction could be considerably less. A comparison with more efficient conventional petrol cars that could be developed in the future, would also show lower reductions, although it is possible that the efficiency of fuel cell vehicles would also improve.

Table 3.10 Total Lifecycle Emissions for Fuel Cell Vehicles

Fuel	**CO_2 g/km**			
	[1]	[2]	[3]	[4]
Gasoline partial oxidation reformer (POX)		147		193[2]
Natural gas reformer		83	104	
Methanol reformer	81	130	99	162[2]
H_2 tank, H_2 from steam reformation of natural gas	64	88	109	
H_2 tank, H_2 from electrolysis (EU electricity mix)			262	
H_2 tank, H_2 from electrolysis (French electricity mix[1])			42	
H_2 tank, H_2 from electrolysis (Canadian electricity mix)				237[2]

[1] The French electricity mix contains a high proportion of nuclear power so has a very low carbon intensity.

[2] Estimates for the Canadian Study are based on using a Mercedes Benz A class vehicle for which gasoline emissions are 248 g CO_2 per km, i.e. significantly higher than the petrol equivalent in the other studies.

Sources:
[1] Kolke, 1999.
[2] Hart and Hormandinger 1997 and Hart and Bauen 1998.
[3] Douard, 2000.
[4] Pembina, 2000.

Disadvantages of fuel cells include high costs (although these may fall in the future), and fuel handling and new infrastructure requirements. Niche market penetration is possible by 2005 on a very limited scale; in the longer term the deployment and contribution from fuel cells could be more significant.

3.6.5 Battery Electric Vehicles

Battery electric vehicles are refuelled by electricity from the power grid. Local emissions are therefore eliminated, but lifecycle CO_2 emissions will depend on the electricity source and Brand *et al* (1997) have reported them between +20% and -100% of petrol vehicle emissions.

Disadvantages are low energy capacity, high cost and long refuelling times. Niche market penetration is possible currently, but significant improvements would be needed to increase this in the future (Brand *et al*, 1997).

3.6.6 Options for Aviation

A recent report on estimating emissions from air traffic (Kalivoda, 1998) suggested that reductions in emissions from aircraft could arise from:

- improved engine design;
- improved air craft design to improve aerodynamic efficiency (such as laminar flow control, blended wing body) and to reduce weight (use of lightweight composite materials);

- improvements in aircraft operations through improvements in communications, navigation and surveillance/air traffic management. Potential measures include allowing more direct routes (free routes) that lie outside of conventional air traffic corridors and also reducing vertical separation minima (thus allowing aircraft to fly closer to optimal altitudes).

The achievable improvements in aircraft efficiency between 1995 and 2010 emitted in the study, allowing for a doubling in air traffic, are shown in Table 3.11.

Table 3.11 Projected Improvements in Aircraft Efficiency 1995-2010

Improvement in:	**Change in aircraft efficiency**	
	Baseline	**Low emission scenario**
Aircraft operations	6%	8%
Engine design improvements	7.5%	8.5%
Aircraft design improvements	4.5%	5.5%

Source: Derived from Kalivoda *et al*, 1998.

Other measures that could also make small contributions to reducing fuel consumption include elimination of non-essential weight, speed optimisation, auxiliary power limitation, and reduced taxiing.

The rate at which these measures might be adopted is determined by the rate at which the aircraft fleet is renewed. Acceleration of this fleet renewal is unlikely, taking account of current aircraft production levels and also increasing travel demand which results in longer lifetimes of older craft.

Growth in air traffic may also have an impact on other transport modes, due to the increase in transport to/from the airport. This can lead to increased passenger car transport, or increases in public transport modes (e.g. train links to the airport).

4 BASELINE TRENDS

4.1 PRIMES PROJECTIONS

Within this study, baseline projections of energy demand, including those for transport are being taken from the PRIMES model baseline scenario defined for the ‘Shared Analysis’ project (1999) of DG Energy . The construction of the scenario, which included interactions with EU Member States authorities, included all policy developments that were certain up to the end of 1997. It thus excluded the impacts of the voluntary agreement reached with European car manufacturers (ACEA) [14] in 1999 to reduce the average CO_2 emissions for all new cars to 170 g/km by 2003, and 140 g/km by 2008 (from a current average of about 186 g/km). A similar agreement was reached with Japanese

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[14] As American car manufacturers are all present in the EU, the ACEA agreement covers the emissions from these cars.

(JAMA) and Korean (KAMA) car manufacturers. For simplicity, in this report the ACEA/JAMA/KAMA agreement is referred to as the "ACEA agreement". The impact of these agreements have subsequently been modelled within PRIMES.

CO_2 emissions in 1990 and 2010 as projected by PRIMES are shown in Table 4.1 for a situation with and without implementation of the ACEA agreement[15]. A breakdown of the CO_2 projections by country is shown in Table 4.2. The projection of CO_2 emissions does not include emissions from electricity used to power trains etc (as this is accounted for within the PRIMES model within the electricity generation module). Aviation includes both national and international flights beginning in the EU, but navigation excludes international marine navigation. Air freight is included with air passenger transport, as little data is available to split these two uses.

The driving parameters for the projection are shown in Table 4.3 and average fuel consumption in 1990 and 2010 are show in Table 4.4. Transport demand and fuel use by fuel type are shown Table 4.5. General trends within the PRIMES baseline projections for the passenger sector are:

- Passenger demand in terms of total passenger km increases by 37% between 1990 and 2010, following trends in the growth in GDP and income. There is a significant shift towards the use of trains and particularly air transport, which grows by 157%.
- For all passenger technologies apart from trains, vehicle kilometres follow the trends in passenger kilometres, as there is no change in load factors.
- There is only a small improvement (2%) in fuel consumption of passenger cars by 2010 in the baseline, but implementation of the ACEA agreement improves ***average*** fuel consumption by 17% by 2010. Train transportation improves in efficiency, reflecting new technologies for electrified trains. Fuel efficiency in the aviation sector also improves significantly due to improved engines, aerodynamics and new materials.
- CO_2 emissions from passenger cars increase due to the increase in vehicle kilometres, although the improvements in fuel consumption (and CO_2 emissions) brought about by the ACEA agreement, reduce the increase (from 31% to 11%).
- CO_2 emissions from trains decrease a lot due to increased electrification (and the allocation of these emissions to the electricity generating sector).
- Aviation CO_2 emissions increase substantially due to the increase in demand for air travel, although the improvement in fuel efficiency does moderate this. Aviation fuel consumption declines when the ACEA agreement is implemented, as improved vehicle fuel efficiency and hence lower costs mean that consumers choose car travel over air travel for some journeys.

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[15] However, in the most recent baseline (see the Green Paper of the European Commission *"Towards a European strategy for the security of energy supply"*, COM(2000) 769, November 2000), the projections of transport emissions have increased by 184 Mt of CO_2 implying that the growth of CO_2 from transport would be 41% instead of 25% by 2010. This increase is due to higher projected growth in truck transport as well as in aviation. These latest numbers have not been included in this analysis.

In the freight sector, general trends are:

- Demand for goods transport increases by over half (53%) between 1990 and 2010, with some modal shift from trucks to trains and navigation (water).
- There is some improvement in fuel consumption of trucks and as for passenger transport a more significant increase in the efficiency of train transport.
- The modal shift and improvements in efficiency (plus the allocation of electric train emissions to the generation sector) mean that overall freight related CO_2 emissions increase by only 33% compared to the increase of 53% in demand.

Within the baseline projection, the introduction of novel transportation fuels (bio-fuels, natural gas etc.) and of fuel cells and electric cars is extremely limited, as the high cost of these technologies to consumers limits their uptake.

Table 4.1 Baseline Trends in CO_2 Emissions from Transport (EU15) (Mt CO_2)

	1990 emissions	**Baseline 2010**	**Baseline 2010 with ACEA agreement**	**Change 1990-2010**	**Change 1990-2010 with ACEA agreement**
	Mt CO_2	**Mt CO_2**	**Mt CO_2**	**% change**	**% change**
Passenger					
Cars	367	479	408	31%	11%
Motorcycles	7	8	8	14%	12%
Trains	7	1	1	-89%	-89%
Buses	27	29	29	7%	5%
Aviation[1]	82	153	149	87%	83%
Navigation[2]	11	14	14	24%	22%
Total (passenger)	*500*	*683*	*608*	*37%*	*22%*
Freight					
Trucks	222	296	296	33%	33%
Trains	2	1	1	-62%	-62%
Navigation	9	13	13	40%	40%
Total (freight)	*233*	*310*	*310*	*33%*	*33%*
Total (all)	***734***	***993***	***918***	***35%***	***25%***

[1] Air passenger transport also includes air freight. Figures include domestic and international aviation. [2]Not including international maritime transport.

Source: PRIMES

Table 4.2 CO_2 Baseline Projections by Member State* (Mt CO_2)

	1990 emissions	**Baseline 2010**	**Baseline 2010 with ACEA agreement**	**Change 1990-2010**	**Change 1990-2010 with ACEA agreement**
	Mt CO_2	**Mt CO_2**	**Mt CO_2**	**% change**	**% change**

Austria	15.2	19.4	17.8	27%	17%
Belgium	22.6	33.3	30.9	47%	36%
Denmark	13.3	14.8	13.9	11%	4%
Finland	12.5	14.6	13.5	17%	8%
France	122.1	156.6	144.6	28%	18%
Germany	168.8	215.3	196.0	28%	16%
Greece	17.2	29.5	28.1	72%	64%
Ireland	5.8	10.4	9.6	79%	65%
Italy	96.6	132.1	121.6	37%	26%
Netherlands	30.0	51.9	48.7	73%	62%
Portugal	11.0	19.7	18.3	78%	66%
Spain	65.6	101.3	95.3	54%	45%
Sweden	20.6	25.4	23.1	23%	12%
UK	132.3	168.8	156.6	28%	18%
EU15	***733.8***	***993.1***	***918.0***	***35%***	***25%***

* Luxembourg not modelled separately in PRIMES

Table 4.3 Parameters in the PRIMES projection

	1990	**2010**	**Change 1990-2010**	**1990**	**2010**	**Change 1990-2010**	**1990**	**2010**	**2010 ACEA**	**Change 1990-2010**	**Change 1990-2010 ACEA**
Passenger	***million pkm***	***million pkm***		***million vkm***	***million vkm***		***Mtoe***	***Mtoe***	***Mtoe***		
Cars	3298607	4392101	33%	2006542	2671715	33%	127	165	141	30%	11%
Motorcycles	89035	107891	21%	84795	102754	21%	2	3	3	14%	12%
Trains	265385	441759	66%	4642	9388	102%	2	3	3	49%	49%
Buses	409728	439215	7%	24448	26220	7%	9	10	9	7%	5%
Aviation	159896	411278	157%	1962	5047	157%	28	52	50	87%	83%
Navigation	23872	30784	29%	159	205	29%	4	5	4	24%	22%
Total (passenger)	***4246523***	***5823028***	***37%***	***2122548***	***2815328***	***33%***	***171***	***236***	***210***	***38%***	***23%***
Freight	***million tkm***	***million tkm***		***million vkm***	***million vkm***		***Mtoe***	***Mtoe***	***Mtoe***		
Trucks	934193	1362109	46%	149449	217906	46%	73	97	97	33%	33%
Trains	240589	451528	88%	759	1424	88%	2	3	3	49%	49%
Navigation	197331	288273	46%	132	192	46%	3	4	4	40%	40%
Total (freight)	***1372113***	***2101910***	***53%***	***150339***	***219521***	***46%***	***78***	***104***	***104***	***34%***	***34%***
Total (all)	***5618636***	***7924938***	***41%***	***2272887***	***3034850***	***34%***	***249***	***340***	***314***	***37%***	***26%***

Notes: PRIMES assumes that vehicle load factors do not change over time

Passenger aviation includes air freight

Aviation fuel consumption is projected to decline when the ACEA agreement is implemented, as improved fuel efficiency and hence lower costs mean that consumers choose car travel over air travel for some journeys.

Source: PRIMES

Table 4.4 Fuel Consumption of Transport Modes (EU Average)

	Fuel consumption toe/m vkm			% change from 1990 to	
	1990	**2010**	**2010 (ACEA)**	**2010**	**2010 (ACEA)**
Passenger					
Cars	63	62	53	-2%	-17%
Motorcycles	28	26		-6%	
Trains	373	275		-26%	
Buses	363	364		0%	
Aviation	14030	10205		-27%	
Navigation	23057	22188		-4%	
Freight					
Trucks	488	445		-9%	
Trains	2283	1815		-20%	
Navigation	22887	21951		-4%	

Source: PRIMES

Table 4.5 Transport Demand by Fuel in PRIMES Baseline Projection (not including ACEA agreement)

	Million pkm		**Final energy demand (ktoe)**	
Passenger transports	**1990**	**2010**	**1990**	**2010**
Private cars	3298607	4392101	127090	165455
LPG	84490	86981	2682	2787
Gasoline	2898624	3668848	111447	136759
Diesel	315493	628012	12960	25673
Natural gas	0	870	0	38
Methanol	0	1121	0	41
Ethanol	0	789	0	41
electric engine – electricity	0	1905	0	27
fuel cells – methanol	0	1347	0	30
fuel cells – hydrogen	0	1248	0	30
turbine engine - natural gas	0	980	0	29
Motorcycles	89035	107891	2363	2699
internal combustion engine - gasoline	89035	107833	2363	2698
electric engine – electricity	0	58	0	1
Buses	409728	439215	8879	9533
internal combustion engine	409728	438392	8879	9525
LPG	0	164	0	3
Gasoline	13851	12076	271	263
Diesel	395877	425747	8608	9251
Natural gas	0	125	0	3
Methanol	0	164	0	3
Ethanol	0	116	0	3
electric engine – electricity	0	318	0	2
fuel cells – methanol	0	185	0	2
fuel cells – hydrogen	0	171	0	2
turbine engine - natural gas	0	149	0	2
Trains	265385	441759	5119	6483
internal combustion engine - diesel	72300	8898	2189	304
electric engine – electricity	193085	432622	2929	6175
fuel cells – methanol	0	124	0	2
fuel cells – hydrogen	0	115	0	2
Aviation (turbine engine – kerosene)	159896	411278	27528	51500
Navigation	23872	30784	3670	4553
Gasoline	1736	2359	216	294
Diesel	22136	28425	3454	4260

Table 4.5 Transport Demand by Fuel in PRIMES Baseline Projection(continued)

	Million pkm		**Final energy demand (ktoe)**	
Goods transport	**1990**	**2010**	**1990**	**2010**
Road transport	934193	1362109	72867	97030
LPG	0	440	0	25
Gasoline	79651	70626	7210	5713
Diesel	854542	1287303	65657	91116
Natural gas	0	333	0	25
Methanol	0	436	0	28
Ethanol	0	307	0	28
electric engine – electricity	0	1003	0	25
fuel cells – methanol	0	636	0	24
fuel cells – hydrogen	0	589	0	24
turbine engine - natural gas	0	438	0	23
Train transport	240589	451528	1732	2584
internal combustion engine - diesel	55920	20491	661	250
electric engine – electricity	184669	430802	1070	2333
fuel cells – methanol	0	122	0	1
fuel cells – hydrogen	0	113	0	1
Navigation	197331	288273	3011	4219
Gasoline	20002	26620	191	287
Diesel	177329	261653	2820	3932

4.2 COMPARISON OF PRIMES AND TREMOVE

A comparison of pkm, tkm and vkm, between PRIMES and TREMOVE for the nine Member States modelled in TREMOVE (the integrated transport emission forecasting model being used in the European Commission’s AutoOil2 study on transport and urban air quality) shows that:

- Total passenger traffic demand (pkm) in TREMOVE is generally slightly higher and increases more between 1990 and 2010, leading to a greater difference in 2010.
- Passenger car pkm, vkm and vehicle load factors compare reasonably well, although, unlike PRIMES, TREMOVE load factors change over time.
- Bus and coach load factors are higher in PRIMES leading to lower vehicle kilometres despite transport demand being fairly similar.
- Freight demand (in tkm) is significantly higher in TREMOVE (by 30% in 1990 and 50% in 2010) and vehicle load factors significantly lower giving much higher vkms.

More details of the comparison, and country by country differences are given in Appendix 4. The traffic forecasts within TREMOVE were supplied by Member States and in some cases show very high growth (of about 2% per annum).

CO_2 emissions are also predicted in the TREMOVE model; the model assumes implementation of the ACEA agreement, but not of any agreement with non-EU producers. The assumptions on improvements in CO_2 emissions within TREMOVE have been agreed with ACEA and are based on a progressive improvement in fuel efficiency. Percentage changes from 1995 to 2010 for CO_2 emissions *from road transport only* in PRIMES and TREMOVE are:

• PRIMES (without ACEA + JAMA/KAMA agreement)	+20%
• PRIMES (with ACEA + JAMA/KAMA agreement)	+10%
• TREMOVE (with ACEA + JAMA/KAMA)	+12%

Agreement in baseline trends for passenger car transport between the two models thus seems relatively good.

It is also possible to compare average CO_2 emissions factors (in g/km) for cars between the two models; these are average CO_2 factors calculated by dividing total CO_2 emissions from cars by vehicle kilometres (Table 4.6). While the reduction in TREMOVE is greater, average values in 2010 are in relatively good agreement.

Table 4.6 Average CO_2 emissions factors for cars (g/km)

Projection	1990	2010	Reduction
PRIMES (EU15 average) base case	183	179	-2%
PRIMES (EU15 average) with ACEA+JAMA/KAMA agreement	183	153	-16%
TREMOVE (EU9 average) with ACEA agreement	197	156	-21%

4.3 VEHICLE TECHNOLOGIES WITHIN PRIMES

Within PRIMES the improvement in vehicle efficiency over time is modelled by allowing the model a choice of three technologies to match transport demand. These are an 'existing technology', an improved technology and an advanced technology. The costs and fuel efficiency of the improved and advanced technology are related to the average cost and fuel efficiency of the existing vehicle technology (in each Member State) in 1995. For example, an 'improved' petrol car is estimated to be 25% more efficient and 15% more expensive than the existing technology, whereas an 'advanced' petrol car is 35% more efficient and 60% more costly (a full set of the factors used in contained in Appendix 5).   The cost and fuel efficiency of the existing technology varies by Member State as it reflects the characteristics of the existing fleet (in terms of size and age). An example for passenger car technologies in Germany is shown in Table 4.7.

Table 4.7 Costs and Efficiencies of Current and Improved Passenger Car Technologies in Germany in the PRIMES Model

	Average (1995)		'Improved' technology		Advanced 'technology)	
	€$_{90}$/vehicle	lt/100km	€$_{90}$/vehicle	lt/100km	€$_{90}$/vehicle	lt/100km
Gasoline	15000	9.0	17250	7.2	23288	4.5
Diesel	17250	7.5	19837	6.0	26781	3.7
LPG	16500	7.5	18975	6.8	25616	4.9
Natural gas	20550	10.4	23632	9.0	31904	6.5
Methanol	15750	8.9	18112	7.1	24452	4.7
Ethanol	16050	12.6	18457	10.1	24918	6.7
Electric	22500	3.4	22950	3.3	25245	2.8
Fuel cell (hydrogen)	22350	5.3	22797	5.1	25077	4.4
Fuel cell (methanol)	21750	5.7	22185	5.5	24404	4.7
Gas turbine	16950	7.3	19492	6.3	26315	4.5

Source: PRIMES.

4.4 PROJECTION OF FUTURE N_2O AND CH_4 EMISSIONS

For road vehicles, N_2O and CH_4 emissions have been estimated using projections of vehicle kilometres and appropriate emissions factors (g of pollutants per km). Vehicle kilometres for petrol and diesel passenger and goods vehicles were derived by converting the passenger-kilometres and tonne kilometre projections to vehicle kilometres using Member State-specific load factors.

The emissions factors used were taken from IPCC emission inventory guidelines (IPCC, 1997) and differentiate between petrol and diesel vehicles and vehicles equipped with catalytic converters. It is assumed that vehicles meeting the EURO 1 standard (or equivalent) are equipped with catalysts; the proportion of vehicles meeting the standard was estimated from vehicle stock information for each Member State, and is shown in Table 1.23. By 2010, it is assumed that turnover of the vehicle fleet will mean that all passenger cars are equipped with a catalytic converter. (Deviations from this assumption are likely to be insignificant and restricted to a few Member States, where the average lifetime of cars in the vehicle fleet is slightly longer.)

As discussed in Section 3.2.1.5, N_2O emissions from vehicles equipped with modern catalysts are thought to be lower than those equipped with early generations of catalysts, and emissions from future vehicles meeting EURO II and IV standards (introduced in 2001 and 2006 respectively) are likely to be even lower. As discussed previously the IPCC recommended emission factor of 0.05 g N_2O/km for vehicles equipped with catalysts is thus thought to be too high for modern and future vehicles, and in the absence of an updated emission factor for European vehicles, the value recommended for use with US Tier 1 vehicles of 0.0288 g/km (US EPA, 1998) (which are thought to lie somewhere between a Euro I/II and Euro III/IV vehicle) is used to estimate emissions in 2010[16]. (The value of 0.05 g N_2O/km is taken as representative for cars fitted with catalytic converters in 1990). More work is required in this area to derive a peer reviewed emission factor which is representative of modern European vehicles and typical European drive cycles.

For non-road transport modes, emissions are calculated on the basis of the fuel use projected in the CO_2 modelling and using emission factors derived from IPCC (1997).

In the business as usual scenario N_2O emissions rise substantially from 1990 to 2010 (Figure 4.1) due mainly to the increase in passenger cars equipped with catalytic converters, and their higher N_2O emissions. There is still some uncertainty in this projection however due to the lack of a European derived emission factor appropriate for new vehicles. Emissions from aviation also increase substantially due to the increase in air transport; emissions from rail decrease due to electrification.

Appendix 1 presents a more detailed analysis of air conditioning and catalytic converters. It can be seen that these are estimated to increase greenhouse gas emissions by some 25 g/km (CO_2 equivalent) per vehicle.

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[16] The average turnover time for cars in is about 11 years, so the fleet in 2010 will include a small number of Euro I and II cars, but will consist predominantly of Euro III and IV vehicles. The use of a single emission factor for all these vehicles is therefore an oversimplification, but is unlikely to introduce further uncertainty into the projection, given the level of uncertainty in the emission factor itself.

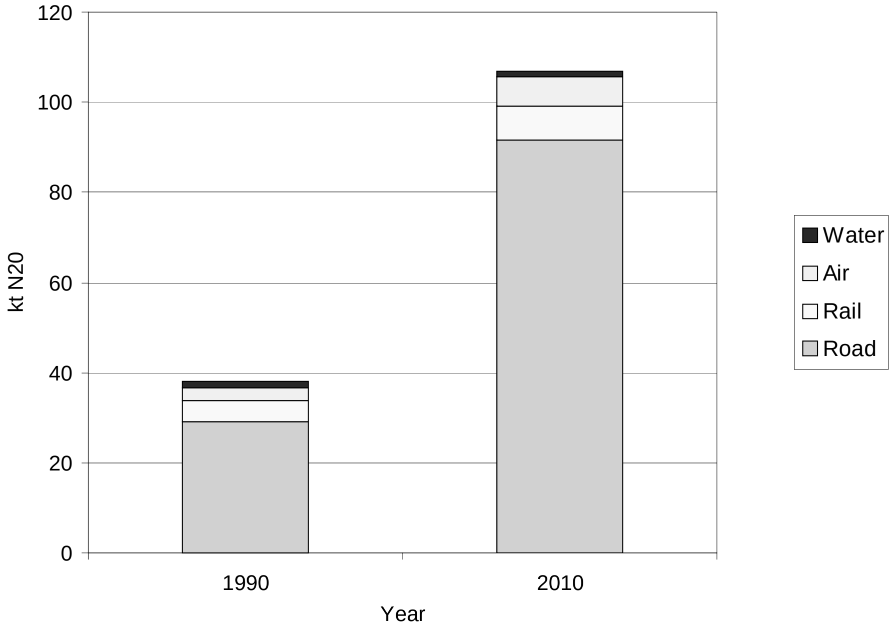
Without the implementation of the End-of-life Vehicle Directive these emissions could be as high as 30 g/km. It seems that mobile air conditioning could increase the nitrous oxide emissions further. Fortunately it seems that lower sulphur content of fuels would reduce nitrous oxide emissions. In sum, between 50 and 60 Mt of additional CO_2 equivalent emissions are projected to emerge in 2010 if no action is taken.

Table 4.8 Percentage of Petrol Vehicles equipped with Catalytic Converters in 1990

Austria	19%
Belgium	2%
Denmark	2%
Finland	6%
France	0%
Germany	21%
Greece	1%
Ireland	0%
Italy	0%
Netherlands	12%
Portugal	0%
Spain	0%
Sweden	14%
United Kingdom	1%

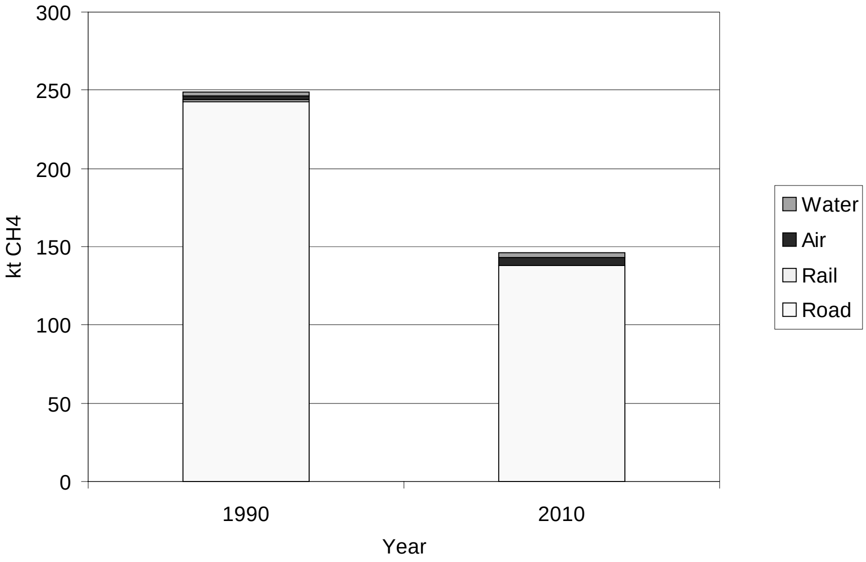
Source: MEET.

Figure 4.1 N_2O Emissions from Transport in Business as Usual Scenario



CH_4 emissions show an opposite trend, with total emissions halving by 2010 for many Member States. Again, this is due to the predicted turnover of passenger car stock to vehicle equipped with catalytic converters, which reduce methane emissions per kilometre. Again, emissions from other transport sources are expected to grow steadily in line with predicted activity growth.

Figure 4.2 CH_4 Emissions from Transport in Business as Usual Scenario



Changes in N_2O and CH_4 emissions by Member State are shown in Table 4.9

Table 4.9 Projected Change in N_2O and CH_4 emissions 1990-2010 (all transport modes)[17]

	1990 -2010 % change	
	N_2O	**CH_4**
Austria	108%	-43%
Belgium	217%	-35%
Denmark	153%	-58%
Finland	173%	-54%
France	236%	-48%
Germany	86%	-46%
Greece	253%	-4%
Ireland	301%	-48%
Italy	248%	-28%
Netherlands	182%	-33%
Portugal	342%	-28%

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[17] Note during the workshop the most appropriate emissions factor to use was redefined and the projections changed slightly. The results presented in the summary report are calculated using the original emissions factor. Overall trends are not affected by the change in emissions factor.

Spain	247%	-35%
Sweden	149%	-50%
United Kingdom	247%	-55%

5 AGGREGATION OF OPTIONS

5.1 PASSENGER CARS

5.1.1 Potential Reductions

The options described in Sections 3.2 and 3.5 have been grouped into ‘packages’ of measures as shown in Table 5.1, with an overall cost-effectiveness and reduction potential which takes account of interaction between the measures. The ‘basic package’ refers to measures to reduce friction and drag (engine friction reduction, aerodynamic drag reduction, rolling resistance reduction and zero brake drag), plus the use of a high strength steel body, all measures which are extensions of existing trends and are available for implementation now. The lightweight structure package includes aluminium body, engine block and a lightweight chassis. Continuously Variable Transmission was not considered to be appropriate for widescale implementation within the EU due to small number of automatic transmission cars.

The CO_2 reduction which might be achieved by each measure has been estimated by estimating the date at which the measure might become available, and how quickly the measure is implemented after this, and using these data to estimate the proportion of the vehicle fleet in 2010 which will be affected by the measure. Full details of the methodology and assumptions made concerning implementation dates are given in Appendix 6; typically technological innovations are initially introduced into ‘top-of-the-range’ vehicles and then diffuse down into mid and bottom-of the range models. Appendix 6 also gives the estimated maximum penetration of diesel in each Member State in 2010, based on current levels, fleet characteristics and penetration in current mature markets. A breakdown of the reductions by Member State are given in Table 5.2. It is possible that reductions are underestimated, as an average annual mileage was used to estimate savings, whereas new cars tend to have a higher than average mileage.

The cost-effectiveness and reductions shown in Table 5.1 and Table 5.2 are for implementation of each measure in isolation. The cost-effectiveness and reductions which would be achieved if all measures are implemented (in order of their cost-effectiveness) is shown in Table 5.3, with a breakdown of the reduction by Member State in Table 5.4.

The interaction between measures is taken account of in the following ways:

- once the advanced GDI engine becomes available, it replaces the VVLT/cylinder deactivation option;
- when the lightweight structure package of measures becomes available, then the high strength steel body element is removed from the basic package;

- implementation of the petrol to diesel shift reduces the number of cars to which petrol only measures may be applied and increases the number of cars to which diesel measures may be applied.

These assumptions over simplify the situation, but were necessary to estimate the reductions which might be achieved due to the simple stock model used for this study. In reality it is likely that complementary technologies will remain on the market place, rather than one technology completely replacing the other. For example, both GDI and VVLT technologies are likely to be available on the market in the future, with GDI tending to dominate in larger engines. Similarly combinations of high strength steel body and lightweight components are likely because the different materials have different advantages with regard to cost, specific weight, rigidity and processing characteristics.

Table 5.1 Cost-effectiveness of Packages of Measures to Reduce CO_2 Emissions from Passenger Cars (Measures implemented individually)

	Cost-effectiveness (including taxes)	Cost-effectiveness (excluding taxes)	Reduction in CO_2 per km		Implementation date	Total % of 2010 Cars with Measure	Total reduction in 2010
	€ /t CO2	**€ /t CO2**	**%**	**g per km**			**MtCO2**
PETROL							
Lightweight Interior Components	-227	8	1.2%	2	2005	19.0%	1.1
VVLT+Cylinder Deactivation	-212	19	14.7%	27	2000	31.0%	22.0
Petrol-Diesel	-131	84	20.0%	36	2000	8.0%	7.8
Advanced GDI (DISC)	-119	93	20.0%	36	2005	19.0%	18.4
Basic	-82	123	5.3%	10	2000	34.5%	8.8
Lightweight Structure	39	218	10.4%	19	2005	19.0%	9.6
DIESEL							
Lightweight Interior Components	-96	41	1.2%	2	2005	3.25%	0.1
Basic	100	196	5.3%	7	2000	5.91%	1.1
Lightweight Structure	263	325	10.4%	14	2005	3.25%	1.2

Table 5.2 Breakdown of CO_2 Reductions from Passenger Cars by Member State (Measures Implemented Individually) (kt CO_2 in 2010)[18]

	Austria	Bel-gium	Den-mark	Finland	France	Ger-many	Greece	Ireland	Italy	Nether-lands	Port-ugal	Spain	Sweden	UK
Petrol														
Lightweight Interior Components	20	25	17	19	156	233	11	12	193	46	21	85	31	222
VVLT+Cylinder Deactivation	410	504	357	396	3160	4791	168	248	3915	910	425	1713	628	4400
Petrol-Diesel	367	276	162	144	3002	72	100	51	1560	414	113	1293	303	1870
Advanced GDI (DISC)	338	430	286	327	2632	3937	189	207	3253	770	361	1430	519	3740
Basic	163	204	140	157	1263	1901	80	99	1563	367	172	686	250	1779
Lightweight Structure	176	224	149	170	1371	2050	98	108	1694	401	188	745	270	1947
Diesel	294	221	130	116	2402	57	80	41	1248	331	90	1034	242	1496
Lightweight Interior Components	4	10	0.5	1.2	41	42	0.1	1.4	10	1.5	2	10	0.7	16
Basic	34	79	4.1	9.7	329	344	0.6	11.5	79	11.8	16	79	5.4	126
Lightweight Structure	37	86	4.3	10.4	357	371	0.8	12.5	85	12.8	18	86	5.8	138

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[18] Calculated assuming EU-average emission factor

Table 5.3 Reductions from Measures to Reduce CO_2 Emissions from Passenger Cars (Allowing for Interaction between Measures)

	Reduction in CO_2 per km		**Implementation date**	**Total % of 2010 Cars with Measure**	**Reduction in 2010**	**Cumulative Reduction**
	%	g/km			Mt CO_2	Mt CO_2
PETROL						
Lightweight Interior Components	1.2%	2	2005	16.3%	0.9	0.9
VVLT+Cylinder Deactivation	14.6%	27	2000	26.9%	18.6	19.5
Petrol-Diesel	19.8%	36	2000	8.0%	7.6	27.1
Advanced GDI (DISC)	19.8%	36	2005	16.3%	15.3	42.4
Basic	2.0%	4	2000	29.7%	2.8	45.7
Lightweight Structure	6.6%	12	2005	16.3%	5.2	51.8
DIESEL						
Lightweight Interior Components	1.2%	2	2005	5.9%	0.2	0.2
Basic	5.2%	7	2000	10.6%	2.0	2.2
Lightweight Structure	9.7%	13	2005	5.9%	2.0	4.3
TOTAL PETROL AND DIESEL						56.0

Table 5.4 Breakdown of CO_2 Reductions from Passenger Cars by Member State (Allowing for Interaction between Measures)

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	UK
PETROL														
Lightweight Interior Components	15	21	14	17	112	232	9	11	165	38	19	66	25	194
VVLT+Cylinder Deactivation	297	417	303	347	2237	4713	139	229	3389	773	385	1312	527	3809
Petrol-Diesel	290	218	128	114	2373	57	79	41	1233	327	89	1022	239	1478
Advanced GDI (DISC)	208	355	235	280	1862	3871	151	190	2746	635	322	1095	422	3238
Basic	52	75	52	61	398	832	29	41	594	136	69	234	92	685
Lightweight Structure	96	140	93	110	735	1527	59	75	1083	250	127	432	166	1277
DIESEL														
Lightweight Interior Components	8	13	2.6	3.1	74	43	1.7	2.1	31	7.1	4	24	4.7	36
Basic	66	102	20.1	23.9	588	347	11.3	16.5	234	53.2	28	192	35.5	286
Lightweight Structure	67	106	21.5	25.6	604	354	13.8	17.3	251	58.1	29	197	38.6	296
TOTAL PETROL AND DIESEL	**1101**	**1448**	**868**	**981**	**8983**	**11976**	**492**	**622**	**9725**	**2279**	**1072**	**4572**	**1551**	**11300**

5.1.2 Overlap with Baseline Projections

The baseline projection already incorporates a small improvement in the overall fuel efficiency of the fleet, and in the case of the baseline with the ACEA agreement, a more substantial improvement. In both cases, almost all of this improvement occurs between 2000 and 2010.

In order to estimate the overlap between the potential reductions for measures estimated above and the two base cases considered (with and without the ACEA agreement), a revised estimate of CO_2 emissions was made, assuming that the average fuel efficiency of the car fleet remained at 2000 levels. The reductions due to improved fuel efficiency can then be compared with the reductions offered by the measures.

For the baseline without the ACEA agreement, the reductions already incorporated in the baseline are about 14% of the total reductions identified in Table 5.3 (56 Mt CO_2). The total reductions identified are not however sufficient to meet the reductions (83 Mt) in the baseline which includes the impact of the ACEA agreement.

Table 5.5 Estimate of CO_2 Reductions Included in Baselines

	Mt CO_2
Baseline	
Revised projections of emissions in 2010 if average fuel efficiency remains at 2000 levels	487
Projected emissions in 2010 in baseline projection	479
Reductions included in baseline	8
Baseline including ACEA agreement	
Revised projections of emissions in 2010 if average fuel efficiency remains at 2000 levels	491
Projected emissions in 2010 in baseline projection	408
Reductions included in baseline	83

5.2 FREIGHT

5.2.1 Potential Reductions

A similar approach was used to estimate potential reductions in the freight sector. Table 5.6 shows the impact of measures when implemented separately and Table 5.8 allowing for interaction between measures. Table 5.7 and Table 5.9 show the impact of measures by Member State.

Table 5.6 Cost-effectiveness of Packages of Measures to Reduce CO_2 Emissions from Freight Transport (Measures implemented individually)

	Cost-effectiveness (€/t CO_2) including taxes	Cost-effectiveness (€/t CO_2) excluding taxes	Reduction in CO_2 per km	CO_2 Reduction (g per km)	Implementation date	Total % of 2010 Cars with Measure	Total CO2 reduction in 2010, MtCO2
Rolling resistance	-241		3.8%	48	2005	100%	10
Engine Improvements	-232		5.7%	73	2005	22%	4
Aerodynamics - Cab Roof Fairing	-215		3.7%	48	2000	25%	3
Aerodynamics - Cab Roof Deflector	-210		2.4%	31	2000	25%	2
Driver Training – HGV Drivers	-156		5.0%	64	2000	75%	10

Table 5.7 Breakdown of CO_2 Reductions from Freight Transport by Member State (Measures Implemented Individually)

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	UK
Rolling resistance	122	343	136	175	1208	1784	350	92	2498	429	225	1604	131	1387
Engine Improvements	43	115	45	59	407	601	63	31	842	144	74	535	45	578
Aerodynamics - Cab Roof Fairing	30	84	34	43	298	440	86	23	616	106	55	395	32	342
Aerodynamics - Cab Roof Deflector	19	55	22	28	193	285	56	15	399	69	36	256	21	222
Driver Training – HGV Drivers	122	342	136	175	1207	1782	349	92	2496	428	224	1603	131	1386

Table 5.8 Cost-effectiveness of Packages of Measures to Reduce CO_2 Emissions from Freight Transport (Allowing for Interaction Between Measures)

	Reduction in CO_2		Implementation date	Total % of 2010 Cars with Measure	CO_2 reduction in 2010	Cumulative CO_2 reduction in 2010
	%	g per km			MtCO2	MtCO2
Rolling resistance	3.75%	48	2005	100%	10	10
Engine Improvements	5.45%	70	2005	22%	3	14
Aerodynamics - Cab Roof Fairing	3.36%	43	2000	25%	2	16
Aerodynamics - Cab Roof Deflector	2.18%	28	2000	25%	2	18
Driver Training – HGV Drivers	4.40%	57	2000	75%	9	27

Table 5.9 Breakdown of CO_2 Reductions from Freight Transport by Member State (Allowing for Interaction between Measures) (kt CO_2 in 2010)

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	UK
Rolling resistance	122	343	136	175	1208	1784	350	92	2498	429	225	1604	131	1387
Engine Improvements	41	110	44	57	391	579	60	30	810	138	71	515	43	556
Aerodynamics - Cab Roof Fairing	27	77	30	39	270	399	78	21	559	96	50	359	29	310
Aerodynamics - Cab Roof Deflector	18	50	20	25	175	259	51	13	363	62	33	233	19	201
Driver Training – HGV Drivers	107	301	120	154	1063	1569	308	81	2197	377	198	1411	116	1220

It is considered that overall reductions in truck weight would not lead to a reduction in emission overall, as most loads are weight limited, and any reduction in lorry weight would be compensated for by an increase in the payload. Aerodynamic improvements are already in use in many vehicles currently and in order to estimate the potential of the measure, it is estimated that 50% of the fle*et al*ready uses deflectors or fairings and that of the remaining 50%, half could use deflectors and half fairing.

5.2.2 Overlap with Baseline Projections

As with the passenger car sector, the baseline projection for freight includes a small improvement in fuel efficiency. The reductions due to this improvement (Table 5.10) are estimated in the same way as for passenger cars. The reductions (3 Mt CO_2) are far smaller than the reductions identified (27 Mt CO_2) suggesting that there is considerable scope for cost-effective reductions

Table 5.10 Estimate of CO_2 Reductions Included in Baseline for Road Freight Sector

	Mt CO_2
Emissions in 2010 if average fuel efficiency remains at 2000 levels	299
Projected emissions in 2010 in baseline projection	296
Reductions included in baseline	3

5.3 AVIATION

The baseline projection for aviation demand (Section 4.1) includes a 27% improvement in fuel consumption per vehicle kilometre between 1990 and 2010. It is considered, given the current rate of fleet renewals, that improvements beyond this could not be achieved by 2010.

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Appendix 1

Greenhouse gas emissions from mobile air conditioning and catalytic converters

J Bates and J Harnisch

1. INTRODUCTION

As mobile air conditioning is not standard equipment, the effect of the weight of the equipment and the additional fuel consumption due to the use of the equipment are not included in the test cycles. The emissions of hydrofluorocarbons (specifically HFC-134a) from the air conditioning equipment (due to leakage) are not included either. The purpose of this Appendix is to quantify the like orders of magnitude of these two sources of greenhouse gas emissions and suggest how much the emissions are likely to increase by 2010 taking 1990 as the point of comparison.

In the Special Report "Economic Evaluation of Emission Reductions of HFCs, PFCs and SF6 in Europe", mobile air conditioning was identified as one source of relatively inexpensive greenhouse gas mitigation options (see table 1). Such potential was not estimated for the reduction of N_2O emission from catalytic converters due to lack of data.

Table 1: Mitigation options of greenhouse gases from mobile air conditioning

	Abatement potential Mt CO2 eq/year	Average cost /t CO2 eq
Leakage reduction	6.6	5.9
Using carbon dioxide instead of HFC-134a	8.8	22.0
Recovery of HFC of the end-of-life vehicle	3.6	31.0
Total	**19.0**	

Source: Economic Evaluation of Emission Reductions of HFCs, PFCs and SF6 in Europe (available at http://europa.eu.int/comm/environment/enveco/studies2.htm#12)

Catalytic converters were introduced in late 1980's and early 1990's to reduce air emissions. Amongst others, catalytic converters reduce emissions of NO_x, which is a greenhouse gas (albeit not covered under the Kyoto Protocol). This improvement in to some extent offset by an increase in nitrous oxide (N_2O) emissions. Test cycles for measuring greenhouse gas emissions do include catalytic converter as far as the fuel consumption is concerned. However, N_2O emissions are not measured or reported in the test cycles.

2. Greenhouse gas emissions from mobile air conditioning

Mobile air conditioners weigh about 14 kg. The added weight increases the fuel consumption slightly and thus is estimated to induce **1,8 g/km of CO_2** emissions.

The coolant used in the mobile air conditioning system hydrofluorocarbons (specifically HFC-134a) is a very potent greenhouse gas (the Global Warming Potential of this gas is 1300 times CO_2 according to the IPCC guidelines). A modern air conditioner has about 800 grams of HFC-134a, and it is estimated that some 10% of this fluid leaks every year (due to accidents, bad valves, leaks in pipes etc.). The leakage of 80 grams of HFC-134a is equivalent of 104 kg of CO_2 equivalent per year. Assuming that a vehicle travels 13500 km per annum (current EU average), the leakage from the air conditioners is equivalent to **7,7 g/km of CO_2**. During the first years the leakage is likely to be small, but as the vehicle ages, the leakage is likely to increase. It would be important to find out what the age dependent leakage rate of mobile air conditioner is.

The End-of-Life Vehicle Directive requires the vehicle manufacturers to recover the HFC-134a fluids[19]. Assuming the lifetime of the vehicle of 12 years and 13500 km per vehicle the end-of-life vehicle, and assuming that 80% of fluids are covered, this would lead to an equivalent of **1,3 g/km of CO_2** leakage. Without the implementation of the directive the emissions would be significantly higher – equivalent of 6,4 g/km of CO_2. However, as the leakage properties of HFC based air conditioners are not known (only a few end-of-life vehicles having HFC-134a on board exist) it would be important to look into this issue. Anecdotal evidence from vehicle dismantlers of end-of-life vehicles using CFC based air conditioners indicates that the CFC fluids have often evaporated before the car has taken to the recycling plant. If this is the case, also for HFC-based air conditioners the leakage rates used in this Appendix would be underestimates.

As mobile air conditioning is not standard equipment, the test cycle used for measuring greenhouse gas emissions does not include the additional fuel consumption due to the use of the air conditioner. Evidently air conditioners are used more in Southern Europe and in Central Europe, while in Northern Europe the usage is quite limited. According to the tests made in the Oak Ridge National Laboratory (Sand and Fisher 1997), the additional fuel consumption due to air conditioning is equivalent of 12 g/km of CO_2 in Greece, 9,2 g/km in Spain, 8,8 g/km in Italy, 4,5 g/km in Germany and 4,2 g/km in the UK.

To scale these figures to all EU Member States, the cooling degree days would be needed. Unfortunately Eurostat does not have such figures available. Thus, some rules of the thumb were used to scale the figures[21]. Using the projected 2010 passenger car data as weights, the average additional fuel consumption due to mobile air conditioning is estimated at **6,3 g/km of CO_2**.

EPA (1998) reported that when the air conditioner was on, N_2O emissions (of the catalytic converter) increased by 50% on the average. The ratio with air conditioner on/off ranged from 0,9 to 3,4 with an average of 1,5. As air conditioning could indirectly increase N_2O emissions, it would be important to measure this impact with European car fleet.

3. Nitrous oxide emissions from catalytic converters

Cars without catalytic converters emit little N_2O (0.005 g/km) and diesel engines fairly little as well (0.01 g/km). However, cars with catalytic converters emit fairly large amounts of N_2O, mainly during the period when the converter is heating up[22]. The first

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[19] Annex 1 of the End-of-Life Vehicle Directive says: "Treatment operations of end-of-life vehicles:... removal and separate collection and storage of... air conditioning system fluids ...". The question is how effective the collection system is. For the purposes of this Appendix, 80% has been used nothing, however, that there are no reliable estimates of what this number should be.

[21] Portugal were assumed to be the same as Spain. Austria and France was assumed to be half way between Germany and Italy (i.e. 6,7 g/km). Benelux countries were assumed to be the same as Germany. Ireland and Denmark were assumed to be the same as the UK while Sweden was assumed to be 75% and Finland 50%. Of the UK figures (3,2 and 2,1 g/km respectively). These figures need to be corrected once the cooling degree days are known.

[22] It should be noted that catalytic converters remove NO_x, which is a greenhouse gas. The removal of NO_x is made for air quality reasons but this has also a positive climate effect. It may well be that the net effect of the introduction of three-way-catalysts has a positive climate effect. However, this Appendix is concentrating only on the N_2O part.

catalytic converters emitted some 0.05 g/km while the three-way-catalytic converters are estimated to emit some 0.0288 g/km[23]. It is likely that the light-off phase of the newer catalytic converters (EURO III and IV) is somewhat shorter, and thus the emissions would be smaller. As few European vehicles had converters in 1990[24] and as the penetration rate will be 100% (they are compulsory in practice), most of the N_2O emissions from vehicles are all additional. Using the agreed conversion factor of N_2O to CO_2 of the IPCC (310), the 0.0238 (0.0288 – 0.005) grams of N_2O is equivalent of an additional increase of **7,4 grams of CO_2** per kilometre due to catalytic converter, if the point of comparison is a car which did not have a catalytic converter.

If the three-way-catalyst is compared with the first generation catalytic converters, the N_2O emissions will decrease. Thus in those Member States where catalytic first generation converters were used in 1990, the increase of N_2O emissions is tempered.
There is also some evidence that by lowering the sulphur content of the fuel N_2O emissions would also be reduced[25]. Thus, the lowering of sulphur content in petrol in the EU is likely to have a positive impact.

4. Summary of the results

As indicated in the table below, the average European vehicle is likely to emit 25 grams of CO_2 equivalent per kilometre more in 2010 than in 1990, due to the increased emission from mobile air conditioning and of the catalytic converter. Table 2 summarises the figures presented in this Appendix. Figure 1 summarises the results likely additional greenhouse gas emissions by vehicle in the Member States.

The figures could be underestimates because it is assumed 80% of the HFC-134a used in air conditioners is recovered according to the End-of-Life Directive. Further, these results do not take into account the fact that vehicles are optimised for the test cycles that do not include the air conditioner.

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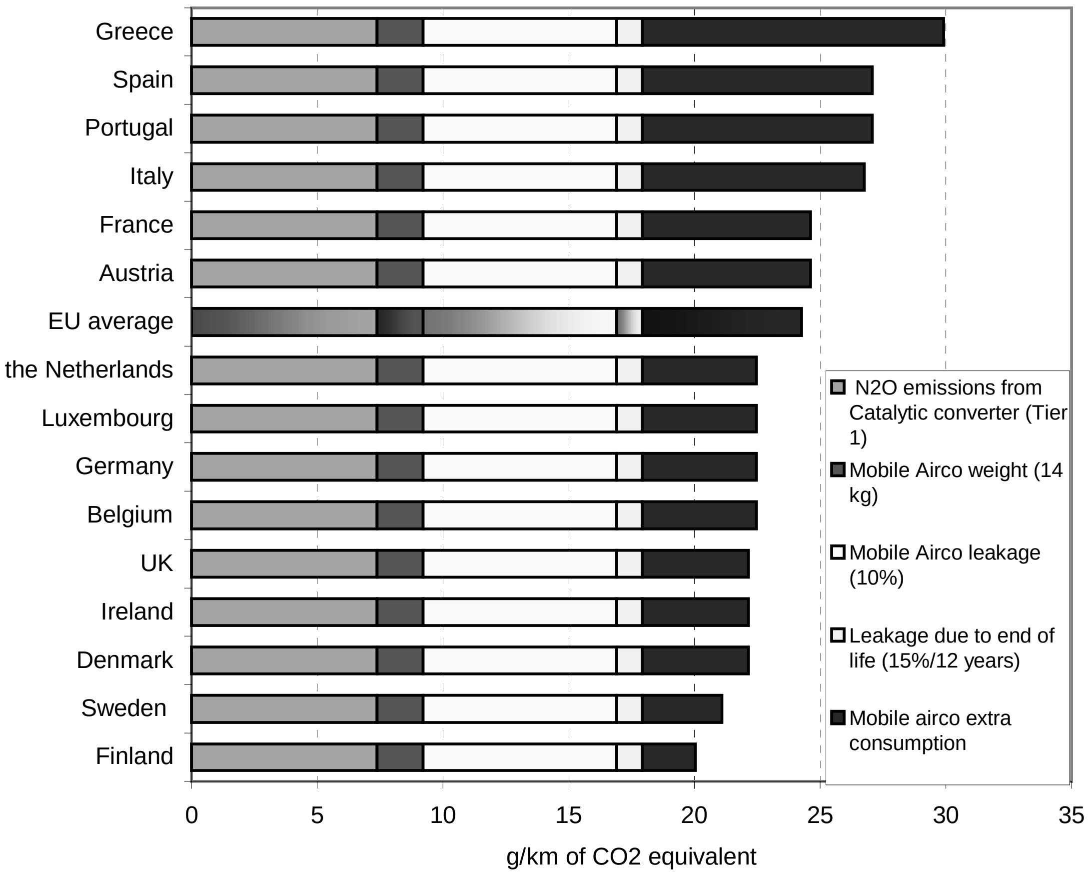
[23] This is based on the study “Emissions of Nitrous Oxide from Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996 (March 1998)." Available at http://www.epa.gov/otaq/climate.htm. The vehicles tested in this study were used cars, thus representing the average fleet. This study was used in “Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories", table "Updated emission factors for USA gasoline vehicles" on page 2.47) available at http://www.ipcc-nggip.iges.or.jp/public/gp/pdf/2_Energy.pdf. Becker et al published another study “Nitrous Oxide Emissions from Vehicles” in Environmental Science and Technology 1999 (33) p. 4134-4139 but that study used new (Ford) vehicles (and alternative fuel specifications) as their basis. Thus these results are likely to be less suitable. No European studies have been carried out on this.

[24] The penetration rates of the first generation catalytic converters (with emission rates of 0.05 g/km, i.e. about twice of the current ones) are in Table 1.23.

[25] The EPA compared two fuel types (“Clean Air Act Baseline” fuel with 285 ppm of sulphur vs. “Indolene” with 24 ppm of sulphur) and found considerable differences in N_2O emissions. (Using “Indolene” fuel reduced the N_2O emissions by some 50% in the experiments). As the sulphur content in the EU will be below 50 ppm (and in average around 30-40 ppm), this is likely to have a positive (but not yet measured) impact on climate.

Figure 1: Projected additional GHG emissions from cars in 2010



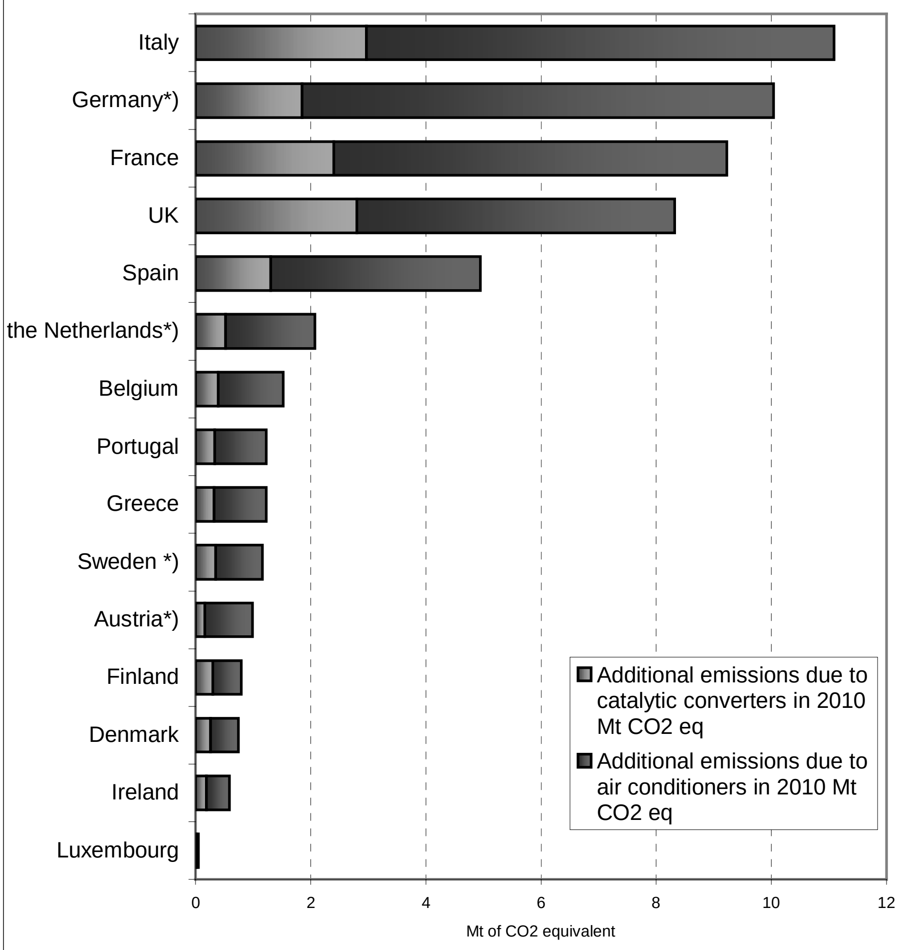
The EU average is calculated using the vehicle kilometres in 2010 as the weight.

Table 2: Average increase in greenhouse gas emissions in the EU due to catalytic converters and mobile air conditioning in 2010, with current technology

	Grams of CO_2 eq per km
CO_2 emissions due to increase weight (14 kg)	1,8
Leakage of HFC-134a (10% per annum)	7,7
Leakage of HFC-134a of end-of-life vehicles (15% lifetime 12 years)	1,3
Extra fuel consumption due to use (weighted average)	6,3
Sub-total air conditioning	17,1
Nitrous oxide emissions from catalytic converters	7,4
Total	**24,5**

Figure 2 shows the likely increase in emissions per Member State. The additional greenhouse gas emissions from these two sources are estimated to be between 50 and 60 Mt of CO_2 eq. emissions in 2010. The increase is to large extent due to mobile air conditioners. Assuming a penetration rate of 90% of mobile air conditioners in 2010, the additional increase greenhouse gas emission is estimated at about 40 Mt of CO_2 eq.

Figure 2: Projected additional GHG emissions due to catalytic converters and air conditioners by Member State in 2010



*) Over 10% of the vehicle fleet had already catalytic converters in 1990.

Taking into account the fact the vehicle fleet had catalytic converters in some Member States in 1990 (see footnote 6), the additional N_2O emissions in 2010 are projected to be about 14 Mt of CO_2 eq. This figure takes into account N_2O emissions from cars without catalytic converters and emissions from first generation converters.

5. Conclusions

The penetration rate of **mobile air conditioning** is currently quite high (e.g. 60% of new vehicles in France) and is likely to be close to 90% in 2010 as consumers are likely to be willing to pay for increased comfort. The technical options to reduce the greenhouse effect need to be investigated by e.g. testing mobile air condition on existing European car fleet. The tests should shed light on leakage rates and additional fuel consumption due to air conditioning. Alternative coolants (in particular CO_2) have been suggested to reduce the greenhouse gas effect (basically to reduce leakage of HFC-134a). However, it should be noted that HFC systems – at least with current technologies – offer better efficiency and thus require lower fuel consumption. It would be helpful if these two off-setting qualities were studied further.

In the case of **catalytic converters** the problem is to have the N_2O emissions be further reduced. There may be some autonomous development due to the fact that vehicles need comply with EURO IV specifications (the light-off phase is likely to shorten). However, as fairly little is known about this subject it would be helpful if the emissions from catalytic converters, including the effect of air conditioning and fuel type (sulphur content) would be tested. It would also be helpful if the test cycles used for vehicle emissions would also include a report of N_2O emissions. To do this properly, the test cycles may need to be modified. Once the testing has been carried out, some further light would perhaps also be shed in how N_2O emissions could be reduced cost-effectively.

Appendix 2

Extract from the report: Economic Evaluation of Emission Reductions of HFCs, PFCs and SF_6 in Europe

SPECIAL REPORT

Contribution to the study
"Economic evaluation of sector targets for climate change"
on behalf of
the Commission of the European Union
Directorate General Environment

Jochen Harnisch and Chris Hendriks

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Final Report
April 25, 2000

FOREWORD

This extract from the original report presents data on the use of HFCs in mobile air conditioning and in refrigerated transport, and subsequent emissions. It also includes estimates of the cost-effectiveness of options to reduce these emissions. Further details of the study and methodology used can be found in the full report.

Mobile air conditioning

Background: Mobile air conditioning is one of the major sources of halocarbon emissions due to rather large specific leakage rates. Emissions are dependent on multiple factors which are quite uncertain. Among them are: number of new cars in each year and each country, trends of the share of cars with air conditioning, trends of typical charge per air conditioning system, trends of mean annual leakage rates and trends of mean lifetime of cars and air conditioning system.

Base year emissions: While HFCs were not in use in 1990, air conditioners in new cars are generally filled with HFC-134a since about 1993. In this study passenger cars and utility vehicles were not treated separately because of the minor relevance of the later within the EU. Estimations are based on European new vehicle registration data (1995-1998) provided by the European Automobile Manufacturer Association (ACEA). To calculate 1995 emissions a leakage rate of 15% / yr is applied [Öko-Recherche, 1999] to the estimated bank of HFC-134a in mobile air conditioning equipment (Table 11).

Baseline scenario: It is assumed that alternative refrigerants do not play a significant role in mobile air conditioning until 2012. Based on estimates made by Öko-Recherche [1996] it is assumed that the average amount of HFC per AC-unit linearly decreases from 0.8 kg to 0.6 kg between 1993 and 2012. The effective mean leakage rate is assumed to decrease from 15% / yr to 10% / yr over the same period. Decommissioning is assumed to release 50% of the full charge. A constant lifetime of 12 years for vehicle and AC equipment is assumed. The number of new vehicles per year is assumed to be sustained at the mean level of the period 1995-1998. The share of vehicles equipped with AC is estimated to have increased from 10% to 50% from 1993 to 1997 and assumed to further increase by 2% / yr thereafter. Emission estimates are given in Table 11. (If the effect of implementing the End-of-Life Vehicle Directive which will require the collection of HFCs from old vehicles is included (see abatement options) then baseline emissions in 2010 fall from 17.7 to 14.1 Mt CO_2 eq.)

Table 11 Estimates of bank of HFC-134a and leakage and decommissioning emissions from mobile AC systems in passenger and utility vehicles.

	Bank HFC-134a [t		Leakage Emission [t / yr]		Decommissiong Emissions [t / yr]		Total Emissions [Mt CO_2 eq/yr]	
	1995	**2010**	**1995**	**2010**	**1995**	**2010**	**1995**	**2010**
Austria	130	1,660	20	220	0	80	0.0	0.4
Belgium	180	2,340	30	320	0	110	0.0	0.6
Denmark	70	860	10	130	0	40	0.0	0.2
Finland	40	590	10	80	0	30	0.0	0.1
France	910	11,070	160	1,600	0	550	0.2	2.8
Germany	1,610	20,280	260	2,650	0	910	0.3	4.6
Greece	60	850	10	110	0	40	0.0	0.2
Great Britain	950	12,100	160	1,660	0	570	0.2	2.9
Ireland	50	710	10	100	0	40	0.0	0.2
Italy	890	11,940	140	1,570	0	540	0.2	2.7
Luxembourg	10	180	0	20	0	10	0.0	0.0
Netherlands	220	2,810	40	400	0	140	0.1	0.7
Portugal	100	1,280	20	230	0	80	0.0	0.4
Spain	430	5,760	80	860	0	300	0.1	1.5
Sweden	90	1,210	10	160	0	60	0.0	0.3
EU-15	**5,740**	**73,630**	**960**	**10,120**	**0**	**3,480**	**1.2**	**17.7**

Key abatement options: Three different abatement options were considered. The first involves the introduction of CO_2 high-pressure air conditioning systems [Wertenbach and Caesar, 1998] which could start in 2004. The extra investment is estimated to be roughly $€_{1999}$ 50 per vehicle. Operating cost (basically energy efficiency) is expected to be comparable to conventional systems. The second abatement option covers a continuous leakage rate reduction down to 5% / yr. We estimate that this modification may cost $€_{1999}$ 10 per car. The cost of the third option, the recovery of 80% of the remaining refrigerant charge at the end of life of the vehicle is estimated to cost about $€_{1999}$ 10 per car. Partly, this last option could be implemented through the new EC “End of life of vehicles”-directive, which covers the recovery of fluids from old vehicles. The total extra-investment for new cars in 2010 would be $€_{1999}$ 100m / yr and additional costs for a recovery of HFCs at the end of life of vehicles in 2010 would be near $€_{1999}$ 70m.

Total emissions reductions and the cost-effectiveness of options at different discount rates are given in Table 12.

Table 12 Abatement costs (in deflated 1990 prices) for emission reduction options for the 2010 baseline with different discount rates (DR)

measure	abated emiss [MT CO_2 eq / yr]	abatement cost [$€_{1990}$/ T CO_2 eq] DR=2%	abatement cost [$€_{1990}$/ T CO_2 eq] DR=4%	abatement cost [$€_{1990}$/ T CO_2 eq] DR=6%
Mobile air conditioning: carbon dioxide	8.8	19	22	25
Mobile air conditioning: leakage red.	6.6	5.1	5.9	6.8
Mobile air conditioning: recovery	3.6	30	31	32

Refrigerated Transport

Key abatement options: A significant number of options to reduce halocarbon emissions from the refrigeration sector generally has been described [e.g. Novem/Ecofys, 1997; March, 1998]. Due to the inherent complexity of the sector there is little transparent and representative information on the costs of these abatement options. It would go far beyond the scope of this study to comprehensively fill this gap. Based on expert interviews own indicative cost estimates were derived that are consistent with the sub-division of applications and the emission model used in this study. For this latter reason we use specific mean cost values per ton of installed HFC (Table 13) and calculate abatement costs from mean changes of these specific costs per application and abatement option (Table 14). This approach consciously ignores much of the technological complexity of this field. Values in both tables are first estimates and may require future revisions. These values are used to give the estimates of total achievable reduction and cost-effectiveness of leakage reduction in this sector shown in Table 15.

Table 13 Assumptions[26] on specific mean costs (investment for equipment, energy costs and maintenance costs) per ton of installed HFC Values are indicative and require future improvement.

Application	spec. inv. for equip. [€$_{1999}$/ T HFC]	spec. energy costs [€$_{1999}$/ T HFC / yr]	Spec. maint. costs [€$_{1999}$ / T HFC / yr]
Transport Refrigeration	250,000	120,000	10,000

[*] Values are reported for illustrative purposes only and are not used for cost calculations.

Table 14 Assumptions[27] on relative cost increases and respective emission reduction.

Measure	increase of investment costs [%]	incr. of energy costs [%]	increase of maintenance costs [%]	emission reduction [%]
Transport refrigeration: leak reduction	5%	0%	50%	40%

Table 15 Abatement costs (in deflated 1990 prices) for emission reduction options for the 2010 baseline with different discount rates (DR)

Measure	abated emiss [MT CO$_2$ eq / yr]	abatement cost [€$_{1990}$/ T CO$_2$ eq] DR=2%	abatement cost [€$_{1990}$/ T CO$_2$ eq] DR=4%	abatement cost [€$_{1990}$/ T CO$_2$ eq] DR=6%
Transport refrigeration: leak reduction	2.8	28	29	29

Baseline scenario: Some types of equipment still using CFCs and HCFCs have a rather long lifetime. The bank of HFCs will thus be roughly 50% mature in 2010. Emission estimates for 2010 can be found in Table 16. These emission levels are expected to grow until maturity of the bank is reached and decommissioning losses become relevant for applications other than domestic refrigeration. Refrigerated transport is projected to become the main ‘refrigeration’ emitter due to large estimated banks in merchant ships.

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[26] Concerns about the validity of these estimates have been expressed but it was also conceded that the required data are currently unavailable. The authors of this study would like to emphasise that they have clearly stated the uncertainties and limitations of their approach.

[27] Concerns have been expressed about the validity of these estimates but it was also conceded that the required data are currently unavailable. The authors of this study would like to emphasise that they have clearly stated the uncertainties and limitations of their approach.

Table 16 Emissions of HFC refrigerant from refrigerated transport applications in 2010

	tons / yr
Austria	60
Belgium	80
Denmark	50
Finland	30
France	460
Germany	700
Greece	30
Great Britain	340
Ireland	20
Italy	360
Luxembourg	5
Netherlands	110
Portugal	30
Spain	170
Sweden	70
EU-15	**2,520**

References

March; Opportunities to minimise emissions of hydrofluorocarbons (HFCs) from the European Union; A study for DG III of the European Commission, March-Consulting-Group, September, 1998.

Novem/Ecofys; Het broeikaseffect en het gebruik van HFK's, PFK's en SF_6 - een studie naar het gebruik, de emissie, reductiemoglijkheden en alternatieven; J.J.D. van derSteen and M. van Brummelen, in Dutch, Utrecht, September, 1997.

Öko-Recherche; Aktuelle und künftige Emissionen treibhauswirksamer fluorierter Verbindungen in Deutschland; W. Schwarz and A. Leisewitz, A study for the German Umweltbundesamt, in German, Frankfurt, 1996.

Wertenbach, J. and Caesar,R. An environmental evaluation of an automobile air-conditioning system with CO_2 versus HFC-134a as refrigerant. (Industry Forum on Mobile A/C Alternative Cooling Systems (Phoenix), July 16-18, 1998), 1998.

Appendix 3

Non-technical Transport Measures

As outlined in the main text, non-technical measures can be classified according to their effects into three top-level categories:

- **operational** measures, affecting the amount of pollutants emitted per vehicle-km;
- **strategic** measures, affecting the vehicle-kilometres driven per unit of demand (expressed in passenger-kilometres/tonne-kilometres);
- **demand** measures, directly affecting the demand for travel (expressed in passenger-kilometres/tonne-kilometres).

The first Table below gives a comprehensive list of the potential measures (actual *solutions*), including the most common classes of measures to reduce pollution from traffic such as traffic management (to smooth traffic flow), mode switching and land use. The table also indicates whether these measures are passenger and/or freight, private and/or commercial, urban and/or extra-urban and local and/or national measures. Please note that *technology improvements* and *optimum technology choice* are classified as technical measures for the purpose of this study; this is indicated by the 'white' background.

The second Table gives an overview of the most common *policy levers* and *incentives* that can act upon the *solutions* to encourage or force people to make use of these. This is done in a 2-level structure, including examples that clarify the issues.

Solutions			**Passenger / Freight**		**(2) Private / Commercial**		**Urban / Extra-urban**		**(3) Local / National**	
1st level category	**2nd level subcategory**	**3rd level subcategory**	**P**	**F**	**P**	**C**	**U**	**E**	**L**	**N**
Operational measures *(effect on emissions per vehicle-km)*	*Technology improvements and optimum technology choice*(1)	*Alternative fuels*(1)								
		Fuel-efficient propulsion systems and vehicle design(1)								
		Tail-pipe emissions treatments(1)								
		Improved fuels(1)								
	Good operating and fuel management practices	Effective monitoring of fuel use	✓	✓	?	✓	✓	✓	✓	
		Driver awareness, training and incentive schemes	✓	✓		✓	✓	✓	✓	
		Preventive maintenance	✓	✓	✓	✓	✓	✓	✓	✓
	Traffic management schemes that smooth traffic flow	Removal of bottlenecks	✓	✓	✓	✓	✓	✓	✓	✓
		Urban bypasses	✓	✓	✓	✓	✓		✓	
		Traffic control systems	✓	✓	✓	✓	✓	✓	✓	
		Rail freight freeways		✓		✓		✓		✓
		Signalling synchronisation	✓	✓	✓	✓	✓		✓	
		Efficient management of roadworks	✓	✓	✓	✓	✓	✓	✓	(✓)(4)
		Public transport segregated lanes	✓		✓		✓		✓	
		(Variable) speed limits	✓	✓	✓	✓	✓	✓	✓	✓
		Pavement management	✓	✓	✓	✓	✓		✓	

Solutions			Passenger / Freight		(2) Private / Commercial		Urban / Extra-urban		(3) Local / National	
1st level category	**2nd level subcategory**	**3rd level subcategory**	**P**	**F**	**P**	**C**	**U**	**E**	**L**	**N**
Strategic measures *(effect on vehicle-km driven per unit of demand (passenger-km/ tonne-km))*	Optimising travel routes	Using routing software	✓	✓	✓	✓	✓	✓	✓	
		Vehicle location and direction systems	✓	✓	✓	✓	✓	✓	✓	✓
		Traffic information systems	✓	✓	✓	✓	✓	✓	✓	✓
	Improving load factors	Improved logistics / better utilisation of freight vehicles		✓		✓	✓	✓	✓	
		Green commuter plans	✓		✓		✓	✓	✓	
		High-occupancy vehicle and public transport lanes	✓		✓	✓	✓	✓	✓	✓
		Larger freight vehicles		✓		✓		✓		✓
		Car pooling (organisations)	✓		✓		✓	✓	✓	✓
		Car sharing (for trips)	✓		✓		✓	✓	✓	
		Fleet management systems	✓	✓		✓	✓	✓	✓	
		Logistics integration / information sharing		✓		✓	✓	✓	✓	
		Demand-responsive public transport	✓		?	✓	✓	✓	✓	
	Mode switching	Public transport information	✓		✓	✓	✓	✓	✓	(✓)
		Public transport prioritisation	✓		✓	✓	✓		✓	
		New / improved public transport services, vehicles and infrastructure	✓		✓	✓	✓	✓	✓	
		Increasing public transport frequency	✓		✓	✓	✓	✓	✓	✓
		Pedestrian zones	✓		✓	✓	✓		✓	
		TEN investment (rail)	✓	✓	✓	✓		✓		✓
		City logistics / transhipment centres		✓		✓	✓		✓	
		Public transport interchanges and terminals	✓		✓	✓	✓	✓	✓	(✓)
		Green commuter plans	✓		✓	✓	✓	✓	✓	
		Park & Ride, Bike & Ride	✓		✓	✓	✓		✓	
		Cycle paths and facilities	✓		✓		✓	✓	✓	(✓)
		Efficient freight road/rail interchanges		✓		✓		✓	✓	(✓)
		Parking management (price and availability)	✓		✓	✓	✓		✓	
		Multi-modal ticketing systems / SmartCards	✓		✓	✓	✓	✓	✓	(✓)

Solutions			**Passenger / Freight**		**(2) Private / Commercial**		**Urban / Extra-urban**		**(3) Local / National**	
1st level category	**2nd level subcategory**	**3rd level subcategory**	**P**	**F**	**P**	**C**	**U**	**E**	**L**	**N**
Demand measures *(effect on travel demand (passenger-km and tonne-km))*	Land-use	Distribution of commercial, residential and service areas (to facilitate public transport and minimise induced traffic)	✓	✓	✓	✓	✓		✓	(✓)
		Car-free residential areas	✓		✓	✓	✓		✓	
	Travel substitution methods	Tele-working, tele-conferencing	✓		✓	✓	✓	✓	✓	
		Tele-shopping / home delivery	✓	✓	✓	✓	✓		✓	
	Influencing travel choice (time, route) to reduce congestion	Adjust school, work and shop opening/ closing times	✓		✓	✓	✓		✓	
		Adjust urban delivery times		✓		✓	✓		✓	
		Adjust holiday times in different countries/ states	✓		✓	✓	✓	✓		✓

Notes:
(1) For the purpose of CANTIQUE, these transport solutions are classified as technical measures.
(2) Private and commercial refer to the vehicles affected. In the case of modal shift from cars to public transport, both columns are ticked.
(3) Local (individual, company, Government authority) and national (Government) refer to the levels at which decisions are taken whether or not to implement measures at a given location.
(4) (✓) indicates the option for national control of local decisions (e.g. in the issuing of policy requirements for land-use planning, or the provision of specific subsidies) but excludes the less immediate national influence exercised through information programmes and guidance notes.

Policy Instruments and Levers			**Passenger / Freight**		**Private / Commercial**		**Urban / Extra-urban**		**Local / National**	
1st level category	**2nd level subcategory**	**Examples**	**P**	**F**	**P**	**C**	**U**	**E**	**L**	**N**
Pricing policies and incentives	Road pricing (price differentiation by e.g. vehicle type, technology, occupancy, age)	Cordon pricing	✓	✓	✓	✓	✓		✓	
		Vignettes	✓	✓	✓	✓	?	✓	✓	✓
		Congestion pricing	✓	✓	✓	✓	✓	✓	✓	✓
		Tolls / corridor pricing	✓	✓	✓	✓	✓	✓	✓	(✓)
		Area licensing	✓	✓	✓	✓	✓		✓	
	Public transport subsidies	Higher quality vehicles/ cleaner vehicles	✓		✓	✓	✓	✓	✓	(✓)
		Discounts for commuters	✓		✓	✓	✓	✓	✓	
	Parking charges	Introduction/ increase of parking charges	✓		✓	✓	✓		✓	

Policy Instruments and Levers			Passenger / Freight		Private / Commercial		Urban / Extra-urban		Local / National	
1st level category	**2nd level subcategory**	**Examples**	**P**	**F**	**P**	**C**	**U**	**E**	**L**	**N**
	Scrappage, purchase and retrofit incentives	Scrappage rebate for old vehicles	✓	✓	✓	✓	✓	✓		✓
		Purchase subsidy for new clean vehicles	✓	✓	✓	✓	✓	✓		✓
Taxes	Fuel taxes	Differential fuel tax (e.g. by fuel type, emissions characteristics)	✓	✓	✓	✓	✓	✓		✓
		Introduction of kerosene tax	✓	✓		✓		✓		✓
	Vehicle taxes	Differential annual vehicle tax (e.g. by vehicle type, technology, age)	✓	✓	✓	✓	✓	✓		✓
	Energy and carbon taxes	Differential tax on energy/ CO use (e.g. by fuel, technology)	✓	✓	✓	✓	✓	✓		✓
	Travel-related tax	Kilometre-related taxation	✓	✓	✓	✓	✓	✓		✓
	Taxation of parking (private, non-residential)	Introduction/change of parking tax	✓		✓		✓	✓	✓	(✓)
Regulation	Zone access control/ environmental zoning	City centre restriction to clean vehicles, low-emission zones	✓	✓	✓	✓	✓		✓	
		Piggy-back rail service across the Alps	✓	✓	✓	✓		✓	✓	?
	Introduction of deregulation	Deregulated public transport services	✓		?	✓	✓	✓		✓
	Introduction or enhancing of competition	Liberalised access to national rail infrastructure	✓	✓	?	✓	✓	✓		✓
	Parking regulation	Limits on parking spaces and times	✓		✓	✓	✓		✓	
	Standardisation and new standards	*Fuel quality standards* (1)								
		Fuel efficiency standards (1)								
		Standard loading units and transfer technologies		✓		✓	✓	✓	✓	(✓)
	Speed limits (modification/ enforcement)	More speed cameras	✓	✓	✓	✓	✓	✓	✓	(✓)
	Land-use planning	Appropriate distribution of commercial, residential and service areas	✓	✓	✓	✓	✓		✓	(✓)
	Labelling	Eco-labelling	✓	✓	✓	✓	✓	✓		✓
	Air quality responsive traffic control	Zone access control	✓	✓	✓	✓	✓		✓	
		Free public transport	✓		✓	✓	✓		✓	
		Traffic signal adjustment	✓	✓	✓	✓	✓		✓	
	Urban planning regulations	Relaxation of urban delivery and shop opening/ closing restrictions	✓	✓	✓	✓	✓		✓	
Infrastructure	Investment	Improved / new public transport services and infrastructure	✓		✓	✓	✓	✓	✓	(✓)

Policy Instruments and Levers			**Passenger / Freight**		**Private / Commercial**		**Urban / Extra-urban**		**Local / National**	
1st level category	**2nd level subcategory**	**Examples**	**P**	**F**	**P**	**C**	**U**	**E**	**L**	**N**
		Modal interchanges	✓	✓	✓	✓	✓	✓	✓	
		TEN and high-speed rail	✓	✓	✓	✓		✓		✓
		Cycle paths/ facilities	✓		✓		✓	✓	✓	✓
		Urban bypasses	✓	✓	✓	✓	✓	✓	✓	(✓)
		High-occupancy vehicle and public transport lanes	✓		✓	✓	✓	✓	✓	✓
		Traffic management systems	✓	✓	✓	✓	✓	✓	✓	
		Rail freight freeways		✓		✓		✓		✓
Information and public awareness initiatives	Targeted awareness activities	Green commuter plans	✓		✓	✓	✓	✓	✓	
	Information dissemination	Public transport information	✓		✓	✓	✓	✓	✓	✓
	Provision of benchmarks	Fuel efficiency benchmarking	✓	✓		✓	✓	✓		✓
	Best practice campaigns	Fuel management best practice	✓	✓		✓	✓	✓	✓	✓
		Public transport marketing best practice	✓		✓	✓	✓	✓	✓	✓
Voluntary agreements	Quality partnerships for public transport	Public-private agreements on investment	✓		✓	✓	✓	✓	✓	
	Voluntary certification	Green vehicles certification scheme	✓	✓	✓	✓	✓	✓		✓
Institutional frameworks	Quality standards for public transport contracts	Public-private contracts	✓		✓	✓	✓	✓	✓	✓
	Brokering of co-operation between multiple private sector organisations	Multi-modal ticketing agreements, car pooling and mobility agencies	✓		✓	✓	✓	✓	✓	✓

Notes:
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(2) Private and commercial refer to the vehicles affected. In the case of modal shift from cars to public transport, both columns are ticked.
(3) Local (individual, company, Government authority) and national (Government) refer to the levels at which decisions are taken whether or not to implement measures at a given location.
(4) (✓) indicates the option for national control of local decisions (e.g. in the issuing of policy requirements for land-use planning, or the provision of specific subsidies) but excludes the less immediate national influence exercised through information programmes and guidance notes.

Appendix 4

Comparison of PRIMES and TREMOVE

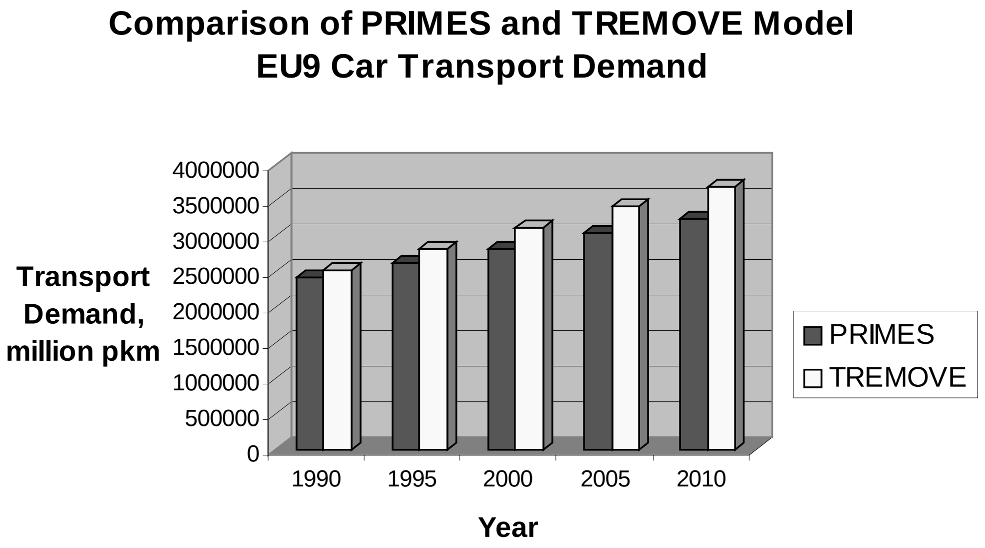
1 INTRODUCTION

The TREMOVE model used in the European Commissons Auto Oil programme covers 9 European Union Member States: Finland, France, Germany, Greece, Irish Republic, Italy, Netherlands, Spain and the United Kingdom. Data and projections for these countries for the period 1990-2010 from the TREMOVE model were compared with data from the PRIMES model used in this study.

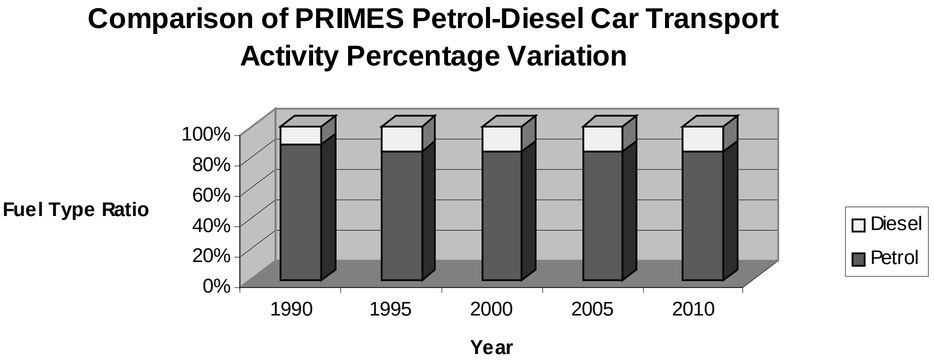
2 GENERAL TRENDS

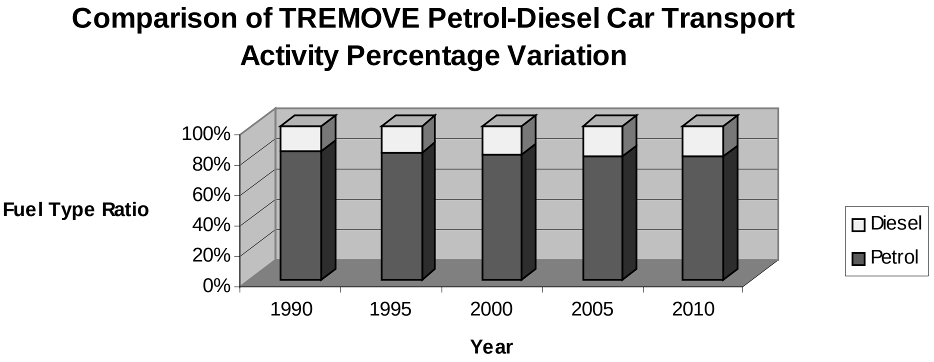
2.1 PASSENGER TRANSPORT

- TREMOVE traffic demand, i.e. passenger kilometers (pk) and tonne km (tkm) are generally larger and it also predicts larger percentage increases between 1990 and 2010 compared to PRIMES, across all transport categories.

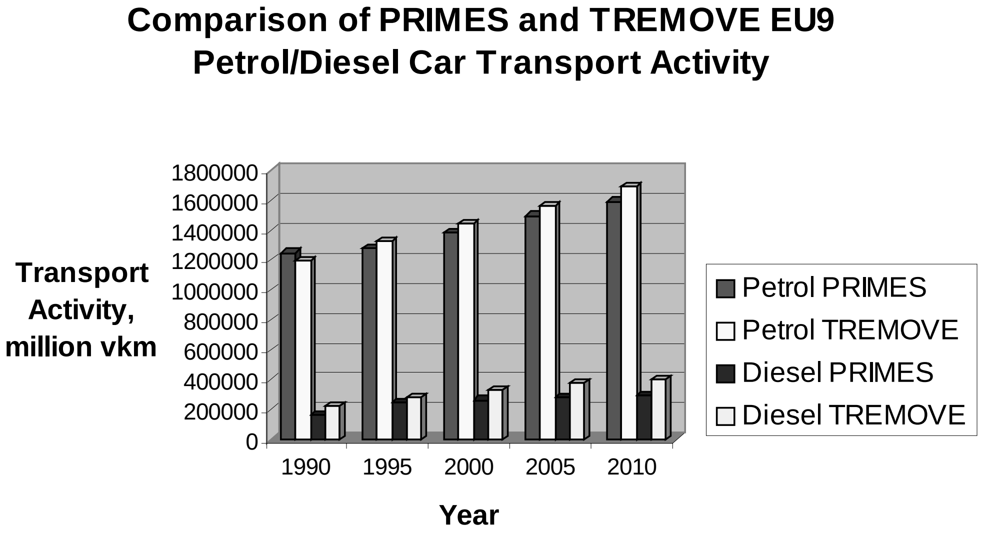


- TREMOVE predicts variation in the average vehicle load factors with time, whilst PRIMES assumes a fixed value throughout the time period.
- Car pkm, vkm and vehicle load factors compare reasonably well across all the 9 EU Member States modelled between 1990 and 2010, although as already mentioned the percentage growth predicted is greater for TREMOVE.


Comparison of PRIMES Petrol-Diesel Car Transport Activity Percentage Variation

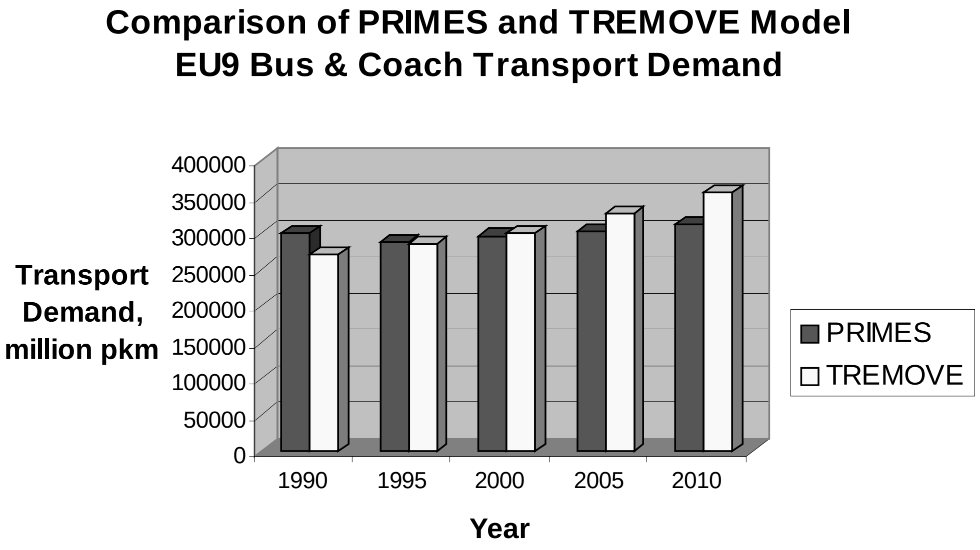

Comparison of TREMOVE Petrol-Diesel Car Transport Activity Percentage Variation

The proportion of car transport demand in pkm between 1990 and 2010 remains around 87% of the total transport demand for both models. However, PRIMES car transport activity (vkm) remain at about 87% of the total, whilst TREMOVE car transport activity remains at 76% between 1990 and 2010 (including trains). This difference is largely due to higher vehicle transport loads in PRIMES for bus, coach and truck transport categories.

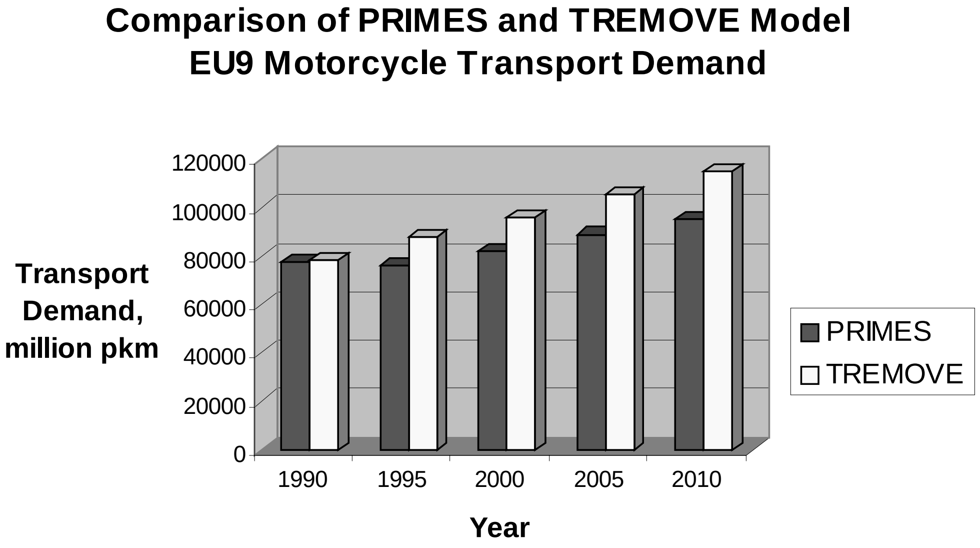

Comparison of PRIMES and TREMOVE EU9 Petrol/Diesel Car Transport Activity

- Both PRIMES and TREMOVE predict an approximate 4% increase in the percentage of diesel car transport activity. However the overall percentages of diesel cars estimated by PRIMES are approximately 4 % smaller than those estimated by TREMOVE.

- PRIMES bus and coach transport demand compare well with the corresponding TREMOVE values, but show a fair degree of variability in agreement across the Member States.
- Vehicle load factors used in PRIMES are generally much larger than those used in TREMOVE (e.g. Spain - PRIMES = 23.5, TREMOVE = 16.8 - 14.2). This has the result of increasing the differences between PRIMES and TREMOVE estimated transport activities (vkm).

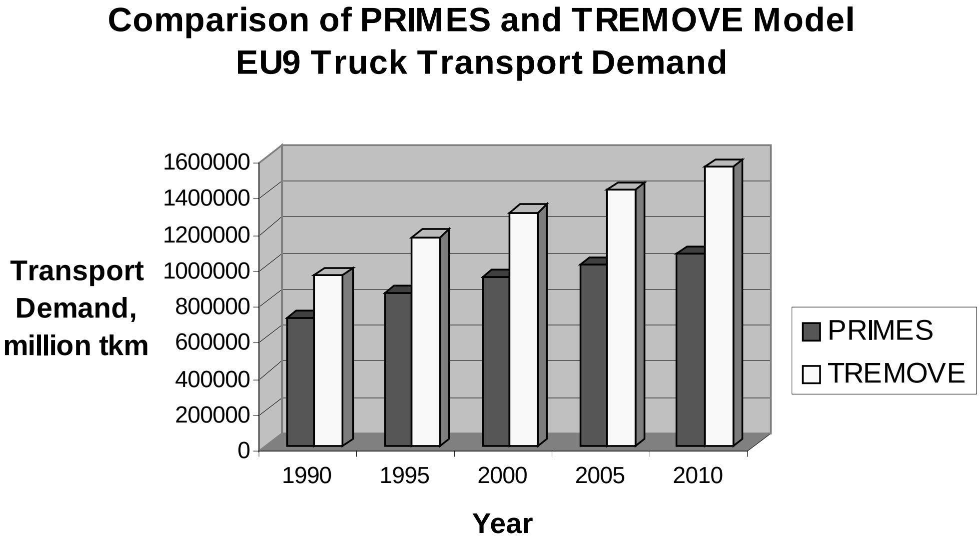

Comparison of PRIMES and TREMOVE Model
EU9 Bus & Coach Transport Demand

- PRIMES motorcycle transport demand shows a fair degree of variability in agreement with TREMOVE values across the Member States. Overall PRIMES values are lower than those predicted using TREMOVE, as is the growth rate.


Comparison of PRIMES and TREMOVE Model
EU9 Motorcycle Transport Demand

2.2 ROAD FREIGHT

- Truck tkm, vkm and vehicle load factors generally do not compare well across all the 9 EU Member States modelled.
- The differences in magnitude of truck traffic demand (tkm) predicted by the two models is pronounced. The combined TREMOVE estimated demands are 30-50% larger than for PRIMES. Again the figures show the larger percentage growth in demand predicted by the TREMOVE model.
- PRIMES vehicle load factors are all larger than the corresponding TREMOVE ones. In some cases the PRIMES value is up too 2-3 times larger.
- PRIMES truck vkm values are much smaller (up to 3 times) than the corresponding TREMOVE vkm values. This difference is only partially accounted for by the differences between the vehicle load values used in the different models.



2.3 COUNTRY SPECIFIC DIFFERENCES

2.3.1 FINLAND

- PRIMES motorcycle transport activities are an order of magnitude smaller than the TREMOVE values.
- PRIMES truck transport activities are significantly lower that the TREMOVE values (e.g. 3,315 million vkm for the year 2000 from PRIMES, compared with 7,054 million vkm estimated by TREMOVE).
- The PRIMES proportion of diesel cars increases whilst the TREMOVE proportion decreases between 1990 and 2010.

2.3.2 FRANCE

- Large differences in bus and motorcycle transport load growth between 1990 and 2010 for PRIMES (1%) and TREMOVE (around 50%).

- PRIMES truck transport activities (vkm) are less than a quarter of TREMOVE values. This is offset to some extent in pkm, as the vehicle load factors are three times the TREMOVE values.

2.3.3 GERMANY

- TREMOVE car transport demands in pkm are 25% more than the PRIMES values.

2.3.4 GREECE

- PRIMES bus and coach vkm transport activities are more than double the TREMOVE values. This is counterbalanced by the vehicle load factors, which are more than half the TREMOVE values.
- PRIMES truck transport activities are about a third of the TREMOVE values. The vehicle load factors are comparable.
- The PRIMES proportion of diesel cars increases significantly between 1990 and 2010, whilst conversely the TREMOVE proportion decreases significantly.

2.3.5 REPUBLIC OF IRELAND

- There is a large difference in predicted growth of bus and coach transport activities between PRIMES (25% increase), compared to TREMOVE (90% increase), between 1990 and 2010.
- PRIMES car transport activities are significantly larger than the TREMOVE values, by almost a third (e.g. 25,151 million vkm compared to19,824 million vkm in the year 2000).
- TREMOVE motorcycle transport activities are more than double those of PRIMES.

2.3.6 ITALY

- Conversely to most of the Member States, PRIMES bus and car transport activities are larger than TREMOVE values.
- In addition, PRIMES bus and coach vehicle load factors are almost half those of TREMOVE (e.g. 14.9 compared to 26.26 persons per vehicle for the year 2000).
- The PRIMES proportion of diesel cars is roughly half that of TREMOVE in 1990, but remains approximately constant while the TREMOVE proportion drops until it is only a third larger than the PRIMES value in 2010.

2.3.7 NETHERLANDS

- Large difference between the projected growth of motorcycle transport demands (pkm) of PRIMES (83% increase) and TREMOVE (1% decrease), between 1990 and 2010.
- Large difference between the projected growth of truck transport demands (tkm) of PRIMES (40% increase) and TREMOVE (106% increase), between 1990 and 2010.
- The PRIMES proportion of diesel cars is several times smaller than that of TREMOVE.

2.3.8 SPAIN

- Poor agreement of PRIMES and TREMOVE bus and truck vkm and pkm data.
- Particularly large differences between bus vehicle load values: PRIMES values are almost double the TREMOVE values. This is opposite to the trend observed for Italy.

2.3.9 UNITED KINGDOM

- Large difference between PRIMES and TREMOVE motorcycle and truck vkm, pkm and vehicle load data.
- The PRIMES proportion of diesel cars of the total number of cars increases from around 3% to about 9% between 1990 and 2010, but the TREMOVE proportion increases from 3% to 19% in the same period.

3 CONCLUSIONS

Agreement between PRIMES and TREMOVE predictions is satisfactory on the EU scale with the exception of the truck category where TREMOVE transport demand estimates are 30-50% larger. However, on the Member State level, predictions can vary considerably for buses and coaches as well as motorcycle categories. Predictions of car transport activities tend to remain fairly similar with only a few exceptions.

Appendix 5

Vehicle Costs and Fuel Efficiency in PRIMES

	Investment per Energy Capacity	Efficiency factor	Maintenance cost
Buses	**€$_{90}$/vehicle**	**lt/100km**	**€$_{90}$/vehicle/year**
LPG	132000	40.6	2750
Gasoline	121000	45.1	2750
Diesel oil	110000	44.8	2750
Natural gas	165000	51.9	2750
Methanol	118800	44.3	2750
Ethanol	121000	62.9	2750
Electricity	154000	17.2	2310
Fuel cell: Hydrogen	220000	26.6	1100
Fuel cell: Methanol	214500	28.7	1100
Gas turbine: Natural gas	137500	36.4	2063
Motorcycles	€$_{90}$/vehicle	lt/100km	€$_{90}$/vehicle/year
Gasoline	3500	4.1	175
Electricity	5250	1.5	79
Private cars			
LPG	16500	7.5	450
Gasoline	15000	9.0	450
Diesel oil	17250	7.5	450
Natural gas	20550	10.4	450
Methanol	15750	8.9	450
Ethanol	16050	12.6	450
Electricity	22500	3.4	225
Fuel cell: Hydrogen	22350	5.3	112
Fuel cell: Methanol	21750	5.7	112
Gas turbine: Natural gas	16950	7.3	254
Passenger trains			
Diesel oil	1000000	521.5	25000
Electricity	1000000	222.4	15000
Fuel cell: Hydrogen	1375000	307.1	6875
Fuel cell: Methanol	1375000	331.7	6875
Aviation			
Gas turbine: Kerosene	5000000	1621.4	250000
Navigation – passengers			
Gasoline	5500000	2185.0	250000
Diesel oil	5000000	1662.7	250000
Trucks			
LPG	102900	56.8	2144
Gasoline	94325	63.1	2144
Diesel oil	85750	52.3	2144
Natural gas	111475	72.7	2144
Methanol	102900	62.0	2144
Ethanol	107188	88.0	2144
Electric	110618	24.1	1659
Fuel cell: Hydrogen	117478	37.2	587
Fuel cell: Methanol	115763	40.1	587
Gas turbine	102900	50.9	1544
Goods trains			
Diesel oil	700000	521.5	21000
Electricity	700000	222.4	7000
Fuel cell: Hydrogen	962500	307.1	4813
Fuel cell: Methanol	962500	331.7	4813
Navigation – goods			
Gasoline	16500000	2185.0	150000
Diesel oil	15000000	1662.7	150000

Appendix 6

Data and Assumptions used to Estimate Total Reductions

Data Requirements:

- Vehicle kilometre data for 2000, 2005 and 2010 was taken from PRIMES. Intermediate data points were estimated using a linear increase.
- The baseline petrol and diesel proportions of the car fleets were calculated from vehicle kilometre data, assuming that the average number of vehicle kilometres was the same for petrol and diesel cars.
- The percentage of new cars added to fleet calculated by the STEEDS model for EU, UK (maximum) and Greece (minimum). Other EU countries are assumed to have the percentage of new cars approximately equal to the EU average.
- The percentage of new trucks data for the EU member states were taken as the same as for cars. The STEEDS model calculation data for UK truck fleet confirmed that the percentage of new vehicles was comparable between cars and trucks.
- Projected diesel penetration estimates for the petrol-diesel shift measure for cars were taken from Bates (1998).
- Emissions rates used for calculation of petrol & diesel cars CO_2 reductions are 182, 135 g CO_2/km respectively (DETR, 1999), and for trucks 1286 g CO_2/km for the year 2000 calculated from PRIMES baseline data.

Country	Projected Diesel Penetration of New Cars*	
	2000-2005	2006-2010
Austria	Current level of 43% maintained	43%
Belgium	45%	45%
Denmark	Linear increase from baseline to 20%	20%
Finland	Linear increase from baseline to 20%	20%
France	Current level of 47% maintained	47%
Germany	20%	20%
Greece	Linear increase from baseline to 20%	20%
Ireland	Linear increase from baseline to 20%	20%
Italy	20%	20%
Luxembourg	Current level of 30% maintained	30%
Netherlands	Linear increase from baseline to 20%	20%
Portugal	Linear increase from baseline to 20%	20%
Spain	Current level of 33% maintained	33%
Sweden	Linear increase from baseline to 20%	20%
UK	Current level of 20% maintained	20%
EU15	Average proportion of 22.46% increases to 26.65%	26.65%

Implementation of Measures

Vehicle Type	Package	Year Available	% New vehicles in Period	
			2001-2005	2006-2010
Cars - Petrol	*VVLT & Cylinder Deactivation*	*2000*	+20% p/a	-20% p/a
	Advanced GDI	*2005*	0	+20% p/a
	Petrol-Diesel Shift	*2000*	Incremental increase up to country maximum*	Maximum maintained
	Basic Package	*2000*	Start = 0, +10% p/a	+10% p/a
	Lightweight Interior	*2005*	0	+20% p/a
	Lightweight Structure	*2005*	0	+20% p/a
Cars - Diesel	*Basic Package*	*2000*	Start = 0, +10% p/a	+10% p/a
	Lightweight Interior	*2005*	0	+20% p/a
	Lightweight Structure	*2005*	0	+20% p/a
Trucks	*Engine Improvements*	*2005*	0	+20% p/a
	Weight Reduction	*2005*	N/A - taken up by additional payload.	
	Aerodynamics - Cab Roof Fairing	*2000*	Start = 25%	50% Total (25% inc.)
	Aerodynamics - Cab Roof Deflector	*2000*	Start = 25%	50% Total (25% inc.)
	Rolling Resistance	*2005*	0	100% by 2010
	Driver Training	*2000*	+15% p/a	Maintain at 75%

* See Bates, 1998

Basic Package:
High strengths steel body, aerodynamic drag reduction, engine friction reduction, rolling reduction and zero brake drag.

Lightweight Structure Package:
Aluminium Body, aluminium engine block and a lightweight chassis.

Advanced GDI (DISC) Engine:
Incorporates VVLT and Cylinder deactivation into a Gasoline (petroleum) Direct Injection engine design.

Methodology

General

- The loss of new vehicles by scrapping is ignored in the calculation of total percent of fleet with measures.
- The average number of km travelled per vehicle is taken to be approximately constant between 2000 and 2010.
- In the application of measures in order of individual cost-effectiveness, it is taken into account that the individual percentage reductions and Cost-effectiveness' are affected by the other measures applied.

Cars

- In the calculation of CO_2 reductions, measures are applied to either the petrol or the diesel portion of the fleet, as appropriate and as reflected by the relevant scenario.
- Since the Advanced GDI engine incorporates VVLT and Cylinder deactivation, the two measures cannot be applied in series.
- When the Lightweight structure package is applied in series with the Basic package, the Aluminium Body replaces the Hi-Strength Steel Body, reducing the contribution of the Basic package to CO_2 reduction.

Trucks

- Reductions in Truck weight are counterbalanced by increased payload for the majority of vehicles, making the measure not practically applicable.
- The aerodynamic improvements are already in use in many vehicles currently. It is estimated that approximately 50% of the fleet currently uses deflectors or fairing. This means that the effective improvements possible in 2010 can be a maximum of 50% in total. A 50:50 split of the two measures is assumed due to differences in applicability of the two measures.

Appendix 7

Participants at Experts Workshops

Participants at Experts Workshop November 23 1999, DG Environment, Brussels

Name	**Organisation**
Experts	
Jean-François Cayot	CLEPA, European Association of Automotive Suppliers
Francisco de la Chesnaye	US EPA
Mats Fredriksson	TEXACO, European Fuels Co-ordinator
Frazer Goodwin	European Federation for Transport and Environment
Winfried Hartung	Adam Opel AG, ITDC PT Legal and Performance Data
Reid Harvey	US EPA
Peter Heinze	Concawe
Tony Houseman	European Association of Aerospace Industries, Environment and Policy
Manfred Kalivoda	PsiA-Kalivoda Consult
Yves Maroger	Renault SA
Jürgen Reifig	European Asphalt Pavement Association c/o DAV
Klaus Schindler	Volkswagen AG
Consultants	
Judith Bates	AEA Technology Environment
David Moon	AEA Technology Environment
Kornelis Blok	Ecofys Energy and Environment
Chris Hendriks	Ecofys Energy and Environment
Leonidas Mantzos	National Technical University of Athens
Commission	
Stefan Winkelbauer	Transport DG E.1 “Analysis and development of transport policy”
Heinz Jansen	Economic and financial Affairs DG E.4“ Environmental policy, transport and energy”
Vicenc Pedret Cusco	Transport DG E.1 “Analysis and development of transport policy”
Leonidas Kioussis	Transport DG C.4 “Airport Policy, environment and other common policies”
Marianne Wenning	Environment DG A.2 ““Climate Change”
Suzanne Doschko	Entreprise DG B.5 “Access to finance and Community programmes”
Daniel Mailliet	Environment DG A.2 “Climate change”
Günter Hörmandinger	Environment DG D.3 “Air quality, urban environment, noise, transport and energy”
Thomas Verheye	Environment DG B.2 Economic Analyses and Employment Unit
Matti Vainio	Environment DG B.2 Economic Analyses and Employment Unit

Participants at Experts Workshop March 30 2000, DG Environment, Brussels

Name	Firm
Experts	
Jean-François Cayot	c/o CLEPA, European Association of Automotive Suppliers
Mats Fredriksson	Texaco
Jean-Loup Gauducheau	Agence de L'Environnement et de l'Energie
Frazer Goodwin	European Federation for Transport and Environment
Winfried Hartung	Adam Opel AG ITDC PT Legal & Performance Data
Alain Henry	TREMOVE
Stephan Singer	WWF European Policy Office
J.W. Turner	ACEA (European Automobile Manufacturers Association) Consultant
Consultants	
Judith Bates	AEA Technology Environment
Kornelis Blok	Ecofys Energy and Environment
Professor Pantelis Capros	National Technical University of Athens E3M – Lab
Chris Hendriks	Ecofys Energy and Environment
European Commission	
Timo Aaltonen	TREN.B.1 Economie sectorielle
Franz-Xavier Soeldner	TREN.A.3 Environment
Jaime Garcia-Rodriguez	TREN.A.3 Environment
Matti Vainio	ENV.B.2 Economic Analyses & Employment
Stefan Vergote	ENTR.F.5