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Cool cars, fancy fuels

A review of technical measures
and policy options to reduce
CO_2 emissions from passenger cars

Report

Delft, November 2005

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Publication Data

Bibliographical data:
B.E. (Bettina) Kampman, B.H. (Bart) Boon
Cool cars, fancy fuels
An review of technical and policy options to reduce CO_2 emissions from passenger cars
Delft, CE, October 2005

Transport / Mobility / Passenger cars / Emissions / Carbon dioxide / Measures / Technology / Fuels / Society

Publication code: 05.4125.37

CE publications are available from www.ce.nl

Commissioned by: WNF
Further information on this study can be obtained from the contact person Bettina Kampman.

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Introduction
In today's world, transport and mobility are of vital importance. At the same time, though, it is one of the major sources of CO_2 emissions, accounting for 20% of these emissions in the Netherlands[1]. These emissions are still on the rise, both in absolute terms and relative to other sectors.

In light of these developments the Dutch branch of the World Wide Fund for Nature, WNF[2], recently decided to focus attention on the CO_2 emissions of cars by launching the campaign 'Frisse Wielen' ('Fresh Wheels'). WNF asked CE Delft to write a research document providing the scientific knowledge base required for this campaign. This report first provides background information on the historical development of CO_2 emissions from passenger cars and the underlying drivers. It then describes the current situation regarding mitigation, including policy measures and technological developments with respect to vehicles and low-carbon fuels. Although car CO_2 emissions can also be reduced via incentives to reduce annual mileage, such measures are not within the scope of this report.

Current state of affairs
In the Netherlands passenger car transport accounts for 10.4% of total CO_2 emissions[3]. Despite 24% projected growth in the aggregate mileage of passenger cars between 2002 and 2020, total CO_2 emissions from these vehicles are
expected to decline by about 4% over the same period[4]. This is because the average CO_2 emission of new cars is decreasing, the combined result of a shift from petrol cars to more fuel-efficient diesel vehicles and ongoing technological developments. However, far greater emission reductions could still be achieved if vehicle weight and engine power did not continue to increase as they have done over the last decade.

Fuel-efficient car technology
The conventional cars on sale today vary widely in terms of fuel efficiency and therefore CO_2 emission factors. The per-kilometre CO_2 emissions of the new models in today's showrooms vary between about 80 and 450 g/km, while the current EU average for new cars is 163 g/km.

Although diesel cars are more fuel-efficient than comparable petrol vehicles, they currently emit more pollutants affecting local air quality. Technology to reduce these emissions is available but not yet mandatory. Switching from diesel to LPG or CNG will not deliver any significant CO_2 reductions.

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1 Excluding emissions from international aviation and maritime shipping.
2 WNF stands for Wereld Natuur Fonds, WWF for the parent organisation.
3 Excluding emissions from international aviation and maritime shipping.
4 Note that total emissions from road transport are expected to grow substantially during this period owing to major growth in freight volumes.

The hybrid cars currently on the market have considerably lower fuel consumption than comparable conventional cars and illustrate the potential of this technology. Nevertheless, a hybrid SUV (sports utility vehicle) is still less fuel-efficient than a smaller conventional car.

Recent studies show that the technology is available to substantially reduce the fuel consumption and thus CO_2 emissions of new passenger cars. Down to about 130 g/km these reductions are even expected to be profitable, with fuel saving benefits outweighing additional vehicle costs. Hybrid drive systems offer great potential for improving fuel efficiency, but other technological improvements to current, conventional engines can also contribute to CO_2 emission reductions.

Fuels

Biofuels are currently the only feasible option for reducing the CO_2 emissions of fuels. Biodiesel and bio-ethanol are expected to come onto the Dutch market next year. Compared with diesel or petrol, these fuels give rise to 30-60% less CO_2 emissions on average. Large-scale biomass cultivation might pose a threat to high-conservation areas and cropland for food production. At present the average cost effectiveness of biofuels is not particularly attractive.

However, there appears to be significant potential for improving the environmental performance of next generation of biofuels. Biofuels embodying a CO_2 reduction of 80-90% are expected to become available in the next 10 years, including bio-ethanol from woody biomass, biomass FT diesel and HTU diesel.

If it is produced from renewable energy sources, hydrogen might be an environmentally attractive option in the longer term. Before this option becomes attractive, however, costs will need to be reduced significantly and a number of technological obstacles overcome.

Policy

In the Netherlands current policy in this area aims to influence consumer purchasing behaviour. Energy labels on new cars inform potential buyers about absolute per-kilometre emissions and fuel efficiency compared with similarly sized models. The Dutch tax regime also provides significant financial incentives for purchasing hybrid cars.

However, some of the technological options for improving fuel efficiency are not currently living up to their potential and are applied only in a small segment of the market. Even improvements costing less than the fuel savings they would achieve are still not always implemented. Additional government incentives are needed to boost the development and sales of more fuel-efficient cars.

One way of doing this would be to set CO_2 emission targets for new passenger cars at the EU level, allowing manufacturers to trade emission rights in pursuit of cost-effectiveness. Long-term goals need to be set so the industry can anticipate the fuel efficiency requirements that will be coming into effect in the future.

Another option would be to introduce financial incentives to encourage consumers to buy fuel-efficient cars. Basing vehicle registration and circulation taxes on fuel efficiency would be a step in the right direction. One segment that could be specifically targeted is the lease market, where market imperfections are even greater because those selecting the car being purchased have virtually no financial motive for choosing a fuel-efficient model.

In general, biofuels are more expensive than conventional fuels and require government incentives before they can be successfully marketed. Additional policies are then needed to guarantee the sustainability of the biofuels used and to encourage development and use of biofuels with superior environmental performance to those currently available. For example, certification of biomass cultivation should be introduced to prevent large-scale biomass cultivation having negative impacts.

In conclusion, rendering private transport sustainable is more than just a technological challenge and transition; it will also require broader changes throughout society. Consumers, car manufacturers, fuel producers, research institutes, governments and NGOs will all need to be involved to steer developments in the right direction and make such a transition possible.

1 Introduction

1.1 Background

In today's world, transport and mobility are of vital importance. At the same time, though, it is one of the major sources of emissions of particulates, SO_2, NO_x and CO_2. Today, transportation is estimated to be responsible for about 20% of CO_2 emissions in the Netherlands[5]. Moreover, CO_2 emissions from Dutch passenger and freight transport continue to rise both in absolute terms and relative to other sectors such as energy and industry. Given the country's emission reduction commitments under the Kyoto protocol, there is growing pressure on the transport sector.

In light of these developments the Dutch branch of the World Wide Fund for Nature, WNF[6], recently decided to focus attention on the CO_2 emissions of cars. The intended strategy for 2005 and beyond has been summarised as follows:
To make a specific, measurable and tangible contribution to the mitigation of CO_2 and other emissions from passenger cars in the Netherlands, not through a decrease in the number of vehicles but through introduction of more efficient and environmentally friendly cars and fuels.

In 2006 WNF is to launch the campaign 'Frisse Wielen' ('Fresh Wheels'), which has the explicit aim of encouraging sales of hybrid cars and climate-neutral and/or climate-friendly fuels. In 2008 WNF aims to have 'a socially and commercially sound and supported vision on developing 'new' mobility in the Netherlands (availability of technologies, infrastructure, regulatory framework and public / consumer attitudes)'.

If successfully launched in the Netherlands, this campaign could be rolled out internationally. The Dutch campaign can thus be seen as a pilot for the 'Carbon by Cars' campaign (working title) envisaged by WWF International.

WNF therefore asked CE Delft to write a clear, straightforward research document providing the scientific knowledge base required for this campaign.

1.2 Scope

This report is concerned with the mitigation of CO_2 emissions from passenger cars. The main focus will be on technologies that are currently available or anticipated in the short term. Emissions from heavy-duty vehicles (freight transport), buses and other modes of transport will not be specifically addressed.

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5 Excluding emissions from international aviation and maritime shipping.
6 WNF stands for Wereld Natuur Fonds, WWF for the parent organisation.

There are three basic ways of limiting car CO_2 emissions:

- By reducing the number of kilometres driven.
- By improving vehicle energy efficiency (i.e. fuel efficiency).
- By using fuels giving rise to lower CO_2 emissions.

This report will focus on the latter two, discussing the technological state of the art and possible future developments as well as current and future policies of relevance.

1.3 Structure of this report

The report is structured as follows. Chapter 2 provides key data on car fleet size and car use and discusses trends in these data. As air pollutant emissions are also an important transport issue, Chapter 3 briefly discusses developments in that field as well as potential synergies and trade-offs between reductions in emissions of CO_2 and air pollutants. Chapter 4 reviews current European and Dutch CO_2 mitigation policies on cars and fuels and looks ahead to potential future policies. Chapter 5 examines the technological options for reducing the CO_2 emissions of cars and fuels, assessing the potential of both currently available and future technologies. In Chapter 6, finally, a number of conclusions are drawn.

2 The overall playing field

2.1 Introduction

In this section we review the main facts, figures and trends regarding car use and ownership. Although the focus will be on the Dutch market, some European data will also be given. This will serve as a background for comparing the developments and potential improvements discussed in later chapters.

The data in this chapter have been taken from different sources. Extensive use has been made of (BOVAG-RAI, 2005) and the information on the website of Statistics Netherlands (Statline, 2005). Many of the data in (BOVAG-RAI, 2005) derive from other, primary sources, which we shall not cite here. Although the geographic and temporal scope of the various sources may sometimes differ, we have nonetheless chosen to include these data in order to 'tell the whole story', unimpeded by paucity of data. This will mean that some statements cannot be grounded in a watertight analysis. We are confident, however, that had more specific data been available a similar picture would have emerged.

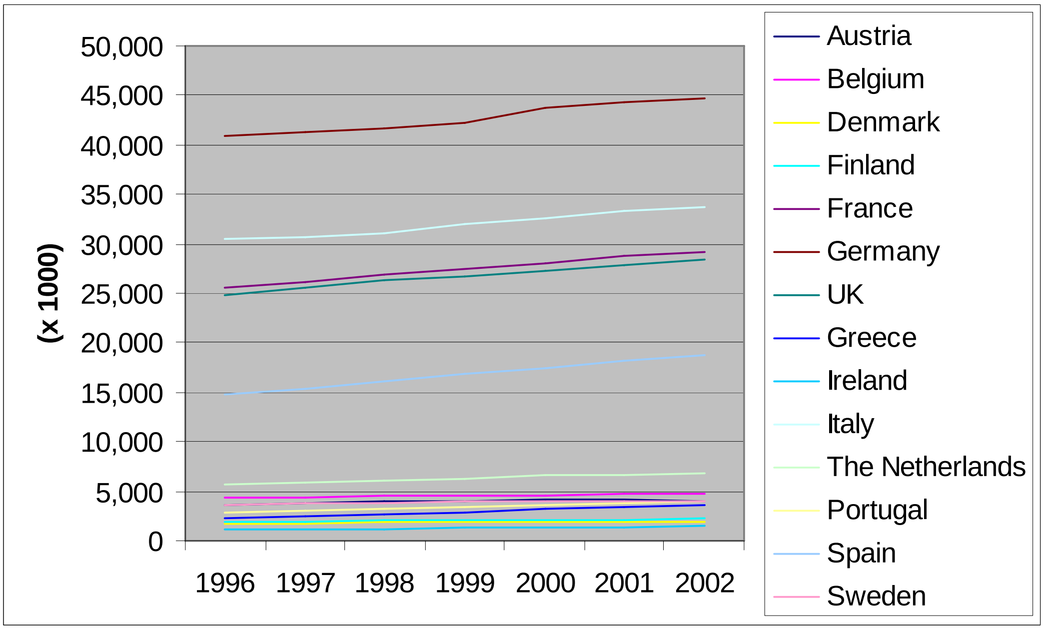
We shall first discuss the car fleet as such, subsequently moving on to examine the more specific features of car use. It should be noted that some of the statistics relate to newly registered cars, others to the existing fleet, and that trends in the former will take some time to influence current fleet performance.

2.2 The vehicle fleet

The number of passenger cars on today's roads continues to grow. This is true of Western Europe and of the Netherlands in particular. Between 1996 and 2002 the aggregate fleet in the fifteen EU countries reviewed in 'a rose from 164 to 187 million cars, an annual growth of about 2.3%. Over the same period the Dutch fleet grew even more: by about 3% annually. As of January 1, 2005 the Dutch passenger car fleet comprised 6,991,991 vehicles.

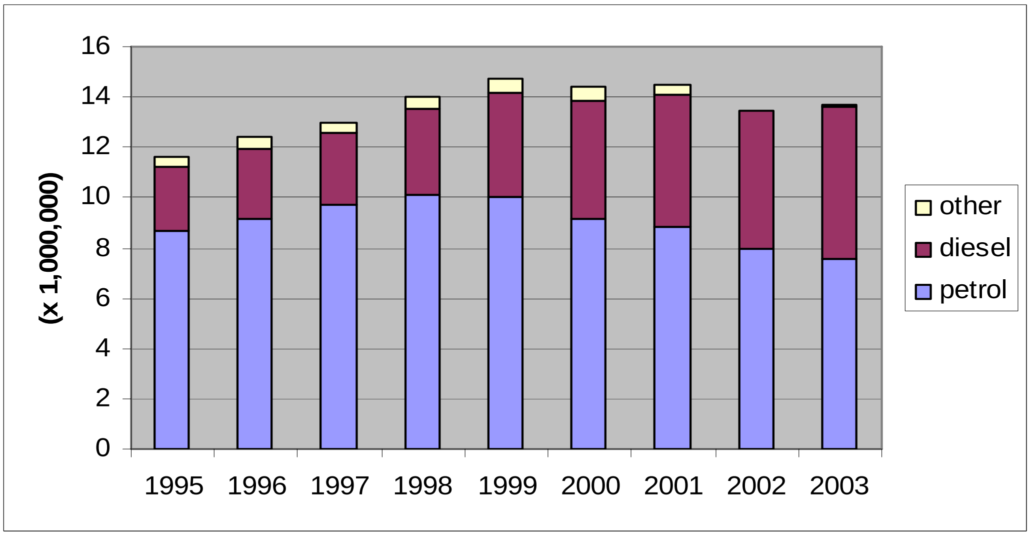
Between 1995 and 2003 sales of new cars in the EU-15 increased by 17%, from about 11.6 million in 1995 to 13.5 million in 2003 (Figure 1).

Figure 1 Historical trends in the passenger car fleet of the EU-15



Source: (BOVAG-RAI, 2005).

Figure 2 Historical trends in passenger car sales in the EU-15

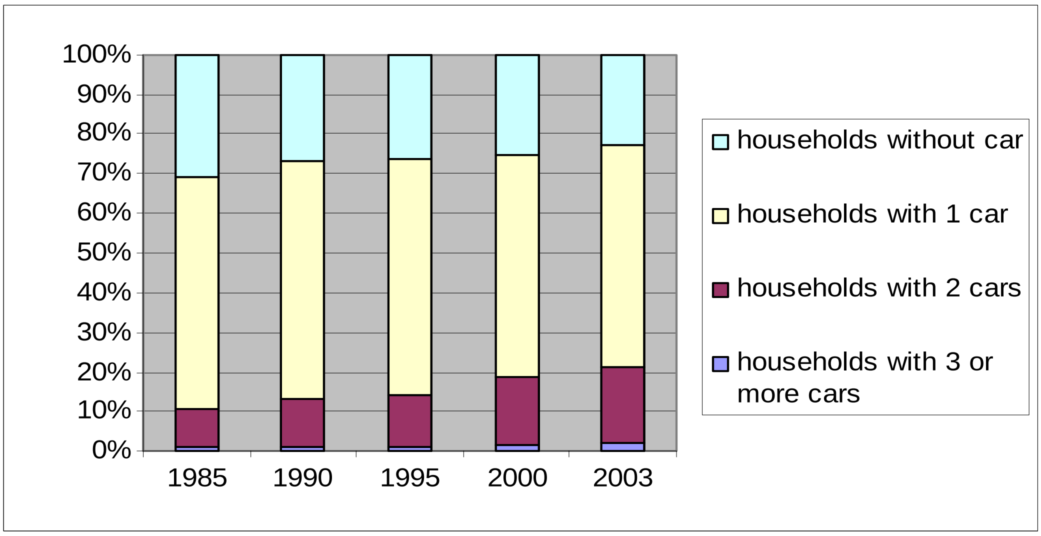


Source: COM(2005) 269 final.

In the Netherlands, per capita car ownership has increased from 1 per 5.4 inhabitants in 1970 to 1 per 2.2 inhabitants in 2005[7]. While in 1985 31% of households did not own a car, by 2003 this had declined to 23% (Figure 3). In the meantime the number of households with two cars doubled, from 9.5% to 19%, despite average household size decreasing over this period.

[7] As a comparison, car ownership in the USA is currently about 1 car per 1.4 inhabitants.

Figure 3 Historical trends in household car ownership in the Netherlands



Source: (Statline, 2005).

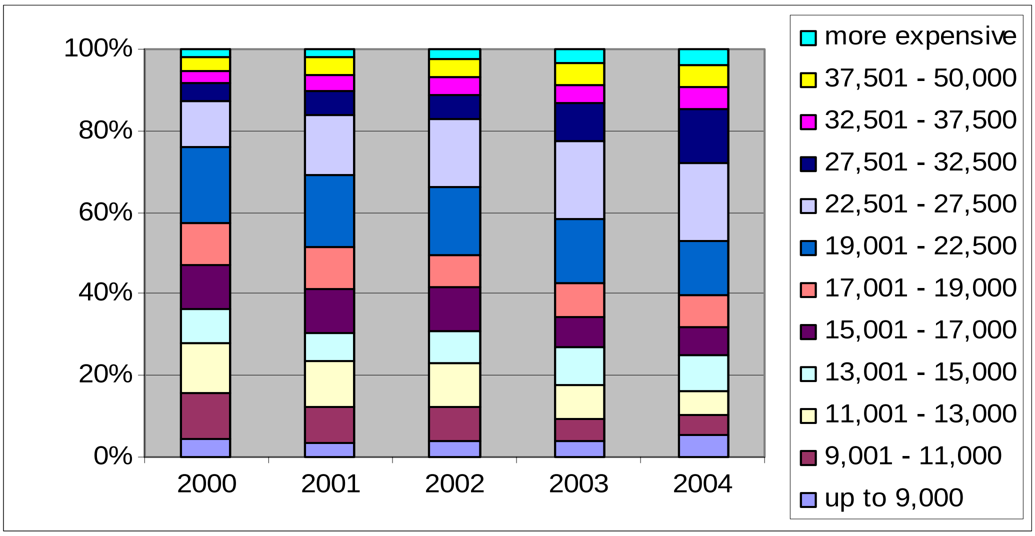
This increase in fleet size is due to a combination of factors. In part it follows from the growth in average income over the years; more people can thus afford a car. Part of the increase can be explained by demographic factors; average households size has decreased and more women are now participating in the job market.

Another explanation for the growth in fleet size lies in the drop in price of *specific* cars by 12% between 1996 and 2004[8] (Eurostat, 2005). This in turn has also influenced the price of used cars. In tandem with growing prosperity, this had led to the current situation in which a private car is within almost anyone's budget.

In contrast to the price of specific cars, the *average* price of the cars purchased is rising, however, as can be seen in Figure 4 and Figure 5. This reflects the fact that personal budgets have grown steadily over the past few decades and that people today are willing to spend more on comfort, safety and luxury.

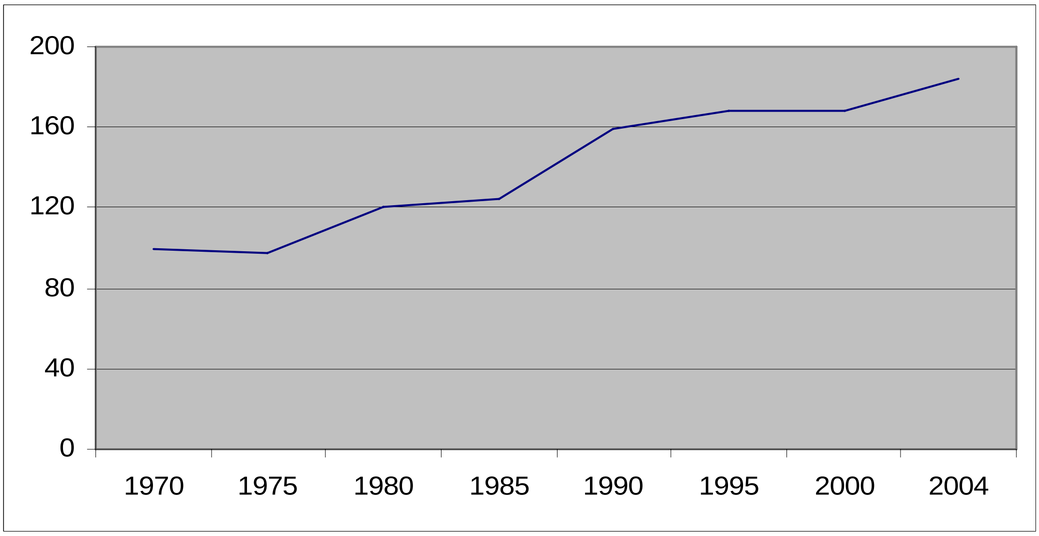
[8] During this period the indexed purchase price of new cars fell from 100 to 88, i.e. the prices of a fixed set of cars, such as a middle-class sedan, decreased on average by 12% over this period.

Figure 4 Composition of newly registered cars in the Netherlands, by purchase price (in Euro)



Source: (BOVAG-RAI, 2005).

Figure 5 Indexed average purchase price of new cars in the Netherlands, corrected for inflation (1970=100)

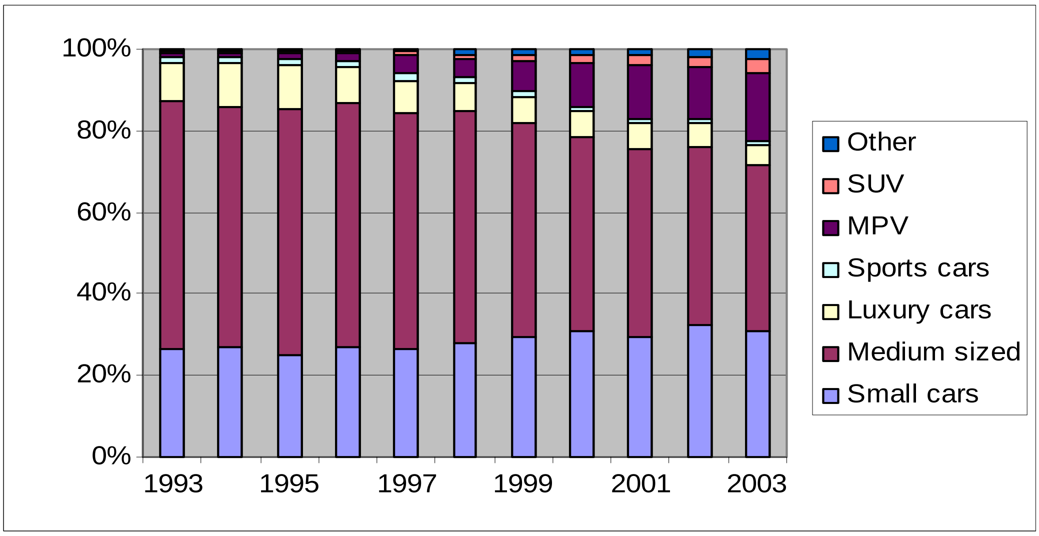


Source: (BOVAG-RAI, 2005).

Not only has there been a shift in the average purchase price of new cars over the years; the types of car bought and their characteristics have also changed. Some of these trends are shown in Figure 6 to Figure 9.

Figure 6 reviews the shares of various market segments in total car sales. As can be seen, there has been a pronounced increase in the market share of SUVs and MPVs (multi-purpose vehicles), from 1.6% in 1993 to 20.2% in 2003. The share of small cars has also increased, although only slightly, probably owing to the rise in the number of households owning two cars. The share of medium sized cars in car sales has declined, on the other hand, as have the shares of sports cars and luxury cars.

Figure 6 Composition of new car sales in the Netherlands, by market segment



Note: See Annex B for examples of the specific car models in each segment.
Source: (BOVAG-RAI, 2005).

Another trend is that more and more people are tending to opt for diesel rather than petrol as a motor fuel, as shown in Figure 7 for the EU. This is due mainly to technical improvements to diesel cars in terms of driving performance (noise, acceleration) and fuel efficiency[9]. The share of diesel-fuelled vehicles in car sales is clearly growing rapidly, leading to further penetration of these vehicles in the European fleet. In the Netherlands the trend towards diesel will be rather less rapid, as the share of diesel vehicles in new car registrations remained more or less stable between 1998 and 2003, at 23%[10].

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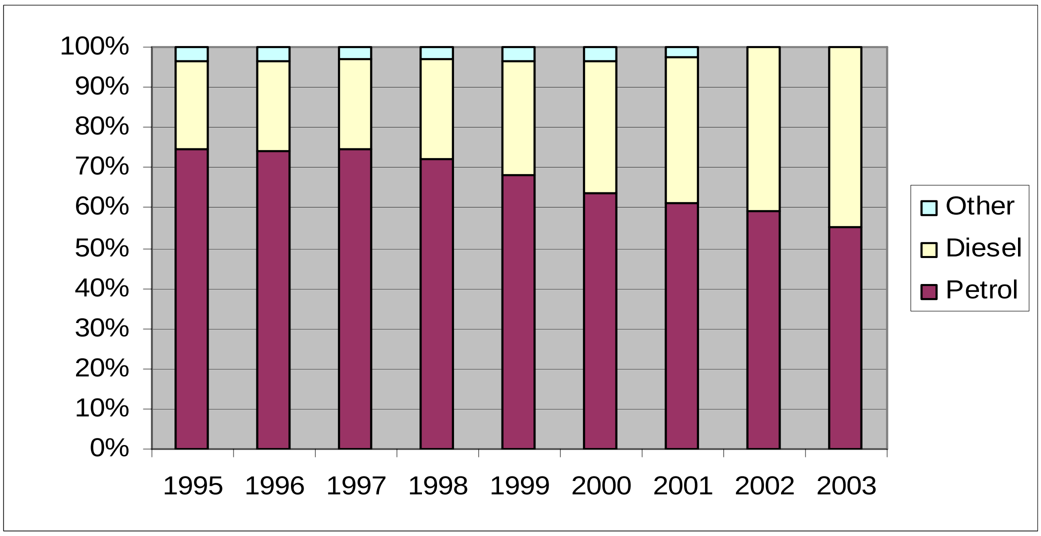
9 Note that diesel is used mainly in larger cars. Of all the 'small' cars sold in the EU 15 in 2002, 22% are diesel. This figure is 49% and 54% for medium sized and large cars, respectively. Source: (IEEP/TNO/CAIR, 2005).

10 One possible explanation is the rise in the registration tax for diesel cars in 2001.

Figure 7 Composition of new car sales in the EU-15

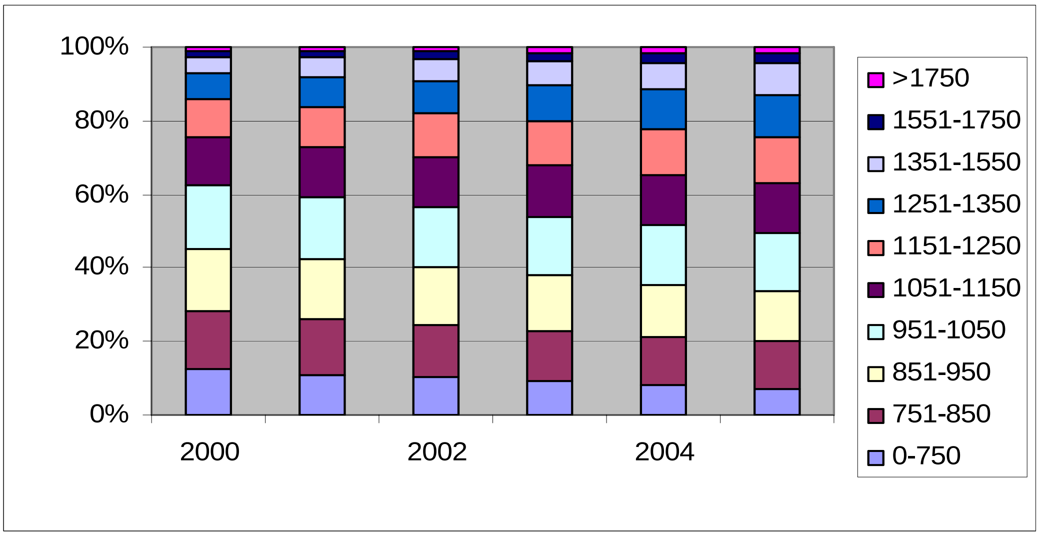


Source: COM(2005) 269 final.

In the Netherlands the share of alternative fuels other than diesel and petrol is small. Of the current Dutch fleet of almost 7 million cars, 81.3% run on petrol and 15.3% on diesel. Petrol cars include the Toyota Prius hybrid, 1,062 of which were sold on the Dutch market in 2004. The share of LPG cars was 3.4% in 2005, down from 11.4% in 1985 and 5.2% in 2000. In 2005 1,669 and 38 cars were powered electrically and used CNG, respectively.

As can be seen in Figure 8, the average weight of cars is increasing over the years. This Figure 8 shows the composition of the Dutch car fleet over the past 5 years. The shift to heavier cars can be explained partly by the shift to MPVs and SUVs cited earlier. However, the weight of cars of the same model and size has also increased, owing to improved safety measures (such as airbags and crumple zones) and comfort (such as air conditioning and CD players, which have become almost standard in every new car).

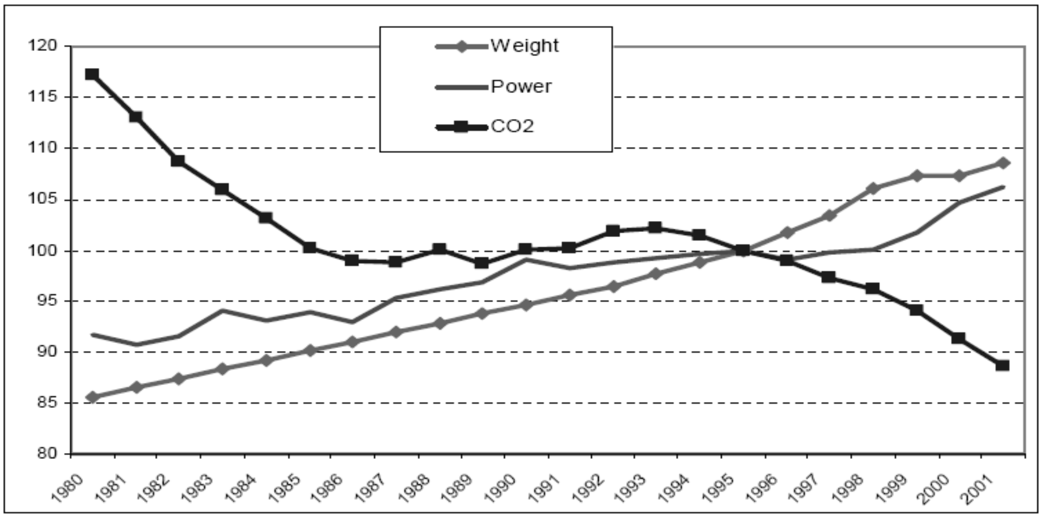
Figure 8 Composition of Dutch car fleet by weight, on first day of year



Source: (Statline, 2005).

Figure 9 reviews European trends with respect to vehicle weight, engine power and CO_2 emissions. As can be seen, the continuous increase in weight has been accompanied by an increase of engine power. Despite these increases, though, the average CO_2 emissions of new cars have declined. Without the increase in weight, average emissions would in all likelihood have declined still further. There is evidence that an additional weight reduction of 100 kg can cut fuel consumption by 0.3 to 0.8 litres per 100 km (cf. discussion in SRU (2005)).

Figure 9 Indexed average CO_2 emissions, engine power and vehicle weight of new European (*) cars by year of registration (1995 = 100)



(*) 8 countries in 1980, 13 from 1995 (EU excluding Greece and Finland), 14 in 2001 (EU excl. Greece). CO_2 emissions during European standard drive cycle.
Source: CEMT/CM(2003)10.

Lease cars are often singled out as a special subsection of the fleet with different characteristics from the average. In 2002 there were 534,000 leased passenger cars on the market in the Netherlands, i.e. about 8% of the total fleet. Lease cars are generally in the upper segments with regard to cost, weight and engine power. They are also relatively new, with hardly any over 4 years' old[11]. As new cars must comply with relatively strict standards and fuel efficiency continues to improve, the lease fleet is relatively clean and fuel-efficient despite consisting of relatively heavy, high-comfort models. In 2004 the share of lease vehicles in new car sales was 25.6%. The share of diesel (and LPG) in the lease market is much higher than in the overall fleet: 47.2% (and 9.7%). The average annual mileage of lease cars is about 31,000 km (TNO, 2002).

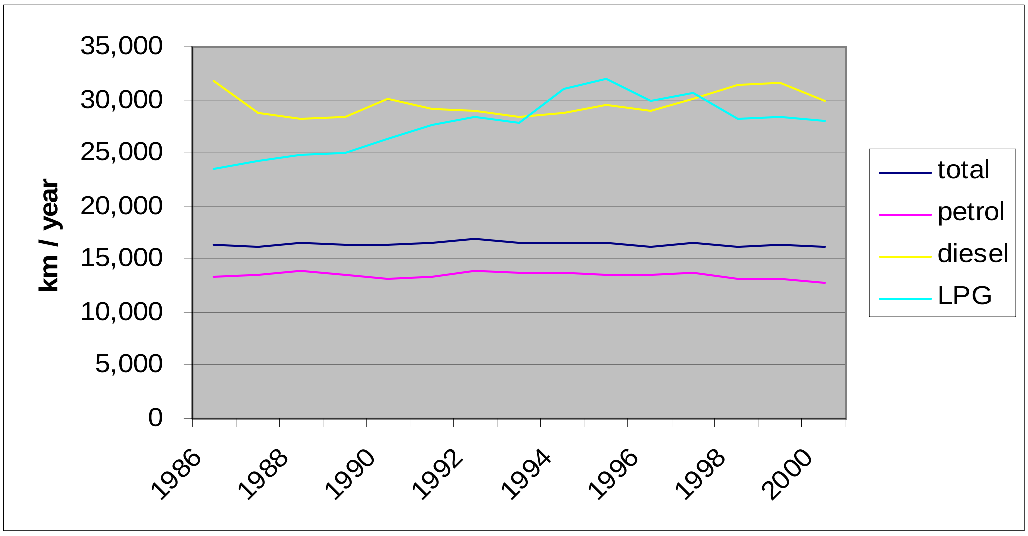
2.3 Car use and CO_2 emissions

The shares of the various fuels in car fleet composition is not the same as their respective shares in total fuel consumption, as average car fuel consumption varies from fuel to fuel. In the first place, the average annual mileage of diesel and LPG cars is much higher than that of petrol cars: around 30,000 kilometres, compared with about 12,500 for petrol vehicles (Figure 10)[12]. This difference is due to the tax structure in force in the Netherlands, where purchase tax on diesel cars is relatively high, as is circulation tax on both diesel and LPG cars. Because the tax on these fuels is relatively low compared to that on petrol, above a certain mileage it becomes financially attractive to switch from a petrol to a diesel or LPG vehicle. Secondly, fuel efficiency differs across fuels, with diesel engines more efficient than petrol engines. Each of these issues will be discussed further, in Section 4.5.1 on Dutch car tax policy and Section 5.4.1 on the fuel efficiency of specific categories of car.

[11] After the first few years they are sold to consumers on the second-hand market.

[12] BOVAG-RAI (2005) note that the most recent year for which information is available is 2001.

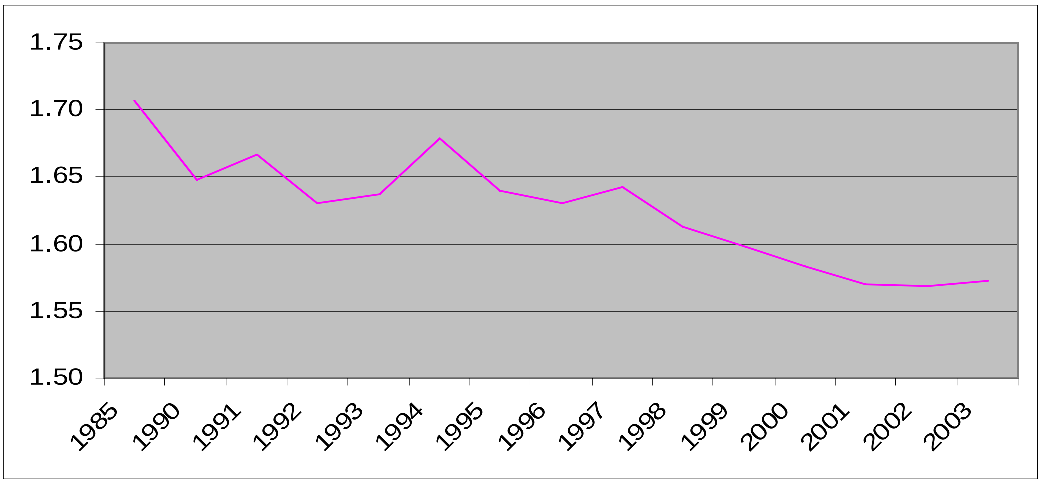
Figure 10 Average mileage of passenger cars in the Netherlands



Source: (Statline, 2005).

With more and more cars owned per capita and average household size declining, car occupancy rates are falling. In 1985 the average number of people in a passenger car in the Netherlands was estimated to be 1.71. This decreased steadily by 8% to 1.57 in 2003.

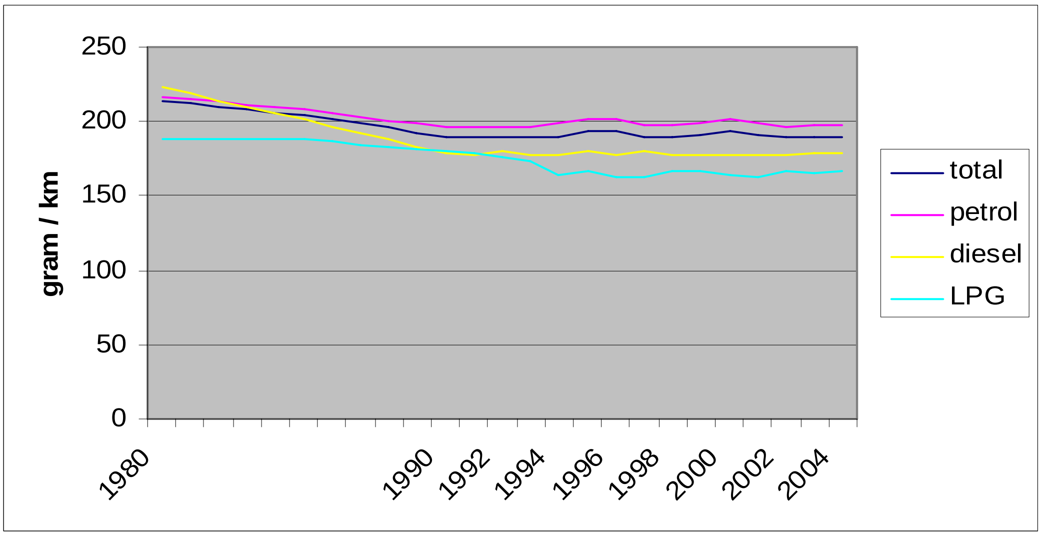
Figure 11 Passenger car occupancy rates in the Netherlands



Source: EEA (2005), fact sheet 29.

Figure 12 reviews the CO_2 emission factors of the Dutch car fleet. Although the average fuel efficiency of diesel cars improved between 1980 and 1990, it has deteriorated slightly over the last few years. This is due mainly to the increase in vehicle weight reported in the previous section.

Figure 12 CO_2 emission factors of the Dutch car fleet



Note: Figures for 2004 are provisional.
Source: (Statline, 2005).

Table 1 shows the performance of the total car fleet in terms of mileage, fuel consumption and CO_2 emissions. For comparison, total Dutch CO_2 emissions of CO_2 were 185 Mtonne in 2002, those of the transport sector (excl. international aviation and maritime transport) 37 Mtonne.

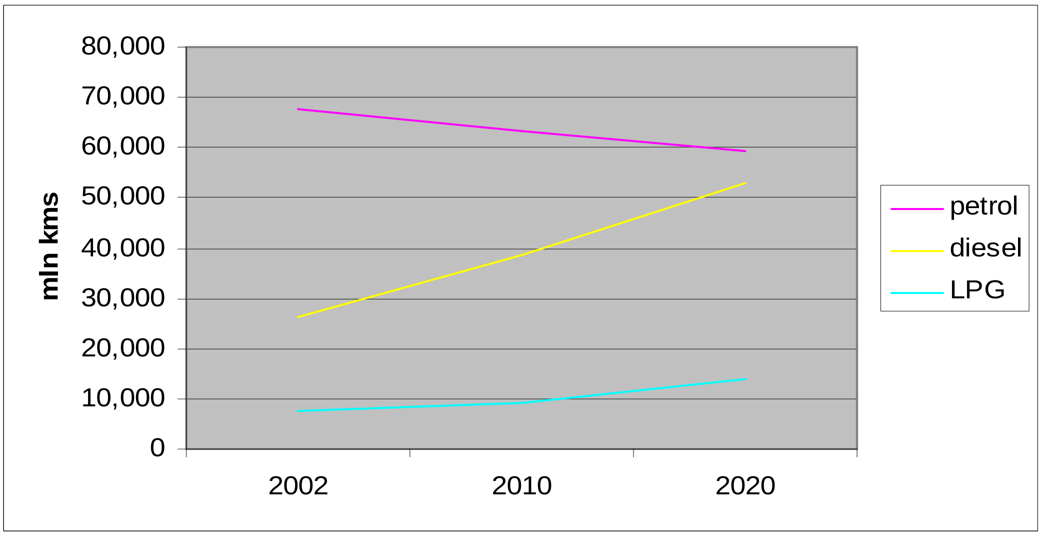
Table 1 Performance of Dutch car fleet according to fuel in 2002

	Petrol	Diesel	LPG	Total
Traffic volume (mln km)	67,792	26,197	7,450	101,439
Fuel consumption (mln litre)	5,606	1,786	779	8,171
CO_2 emissions (Mtonne)	13.3	4.7	1.2	19.3

Note: These figures are provisional.
Source: (Statline, 2005).

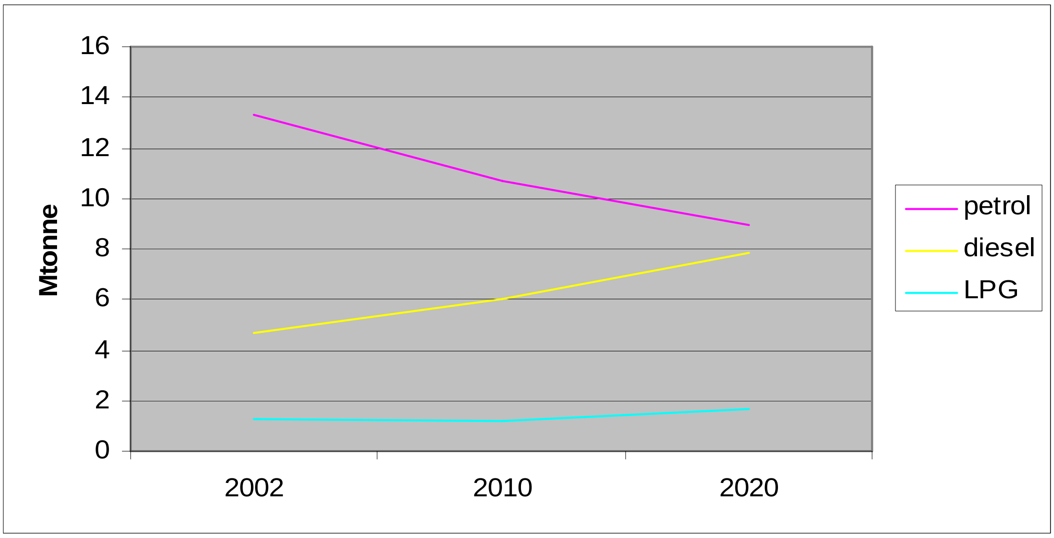
Figure 13 and Figure 14 show RIVM/MNP forecasts of future passenger car traffic volumes and associated CO_2 emissions in the Netherlands. From 2002 to 2020 the total volume of car traffic on the Dutch roads is expected to grow by 24%. Nevertheless, over the same period passenger car CO_2 emissions are predicted to decrease by 4%.

Figure 13 Predicted growth in Dutch passenger car traffic volume



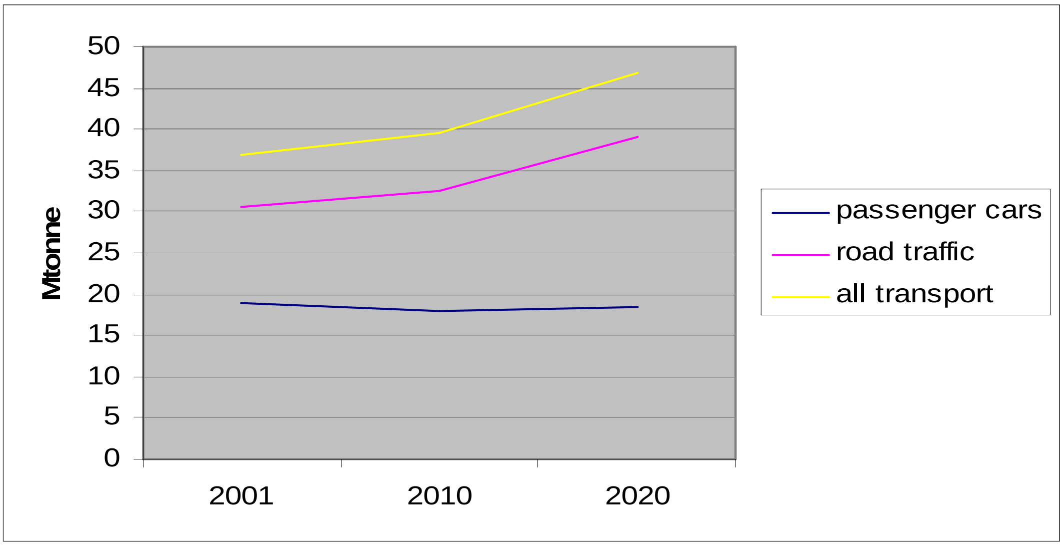
Source: (RIVM/MNP, 2003).

Figure 14 Predicted growth in CO_2 emissions from Dutch passenger cars



Source: (RIVM/MNP, 2003).

Figure 15 Predicted growth in CO_2 emissions from all Dutch transport (*)



(*) Excl. aviation and maritime shipping.
Source: (RIVM/MNP, 2003).

Figure 15 shows the predicted share of passenger cars in overall transport CO_2 emissions (excl. aviation and maritime shipping) through to the year 2020. While passenger car emissions are expected to remain relatively stable over this period, CO_2 emissions from delivery vans are expected to rise by 50% and those from trucks and buses to double between 2001 and 2020.

Besides CO_2 emissions, the air conditioning in many cars also causes emissions of refrigerants like HFC, which are strong greenhouse gases. These emissions are not included in the CO_2 tests for new passenger cars and consequently neither in the above data. The Commission recently launched a tender procedure for development of a measurement procedure for these emissions (COM(2005)269 final). These emissions are also addressed in the EU regulations on fluorinated greenhouse gas emissions currently under development (COM(2003)492).

2.4 Conclusions

The contribution of road transport to total CO_2 emissions is expected to grow in the coming years. Trucks and delivery vans are the main contributors to the growth of road transport emissions. For passenger cars, the growth in transport volume is expected to be offset by improvements in fuel efficiency.

These improvements will be due partly to a shift from petrol to diesel cars and partly to technological improvements. Cars using other fuels will not play any significant role in the coming years. To some extent improved fuel efficiency will be offset by shifts in consumer choices, towards larger and more comfortable cars, for example.

3 CO_2 in relation to other pollutants

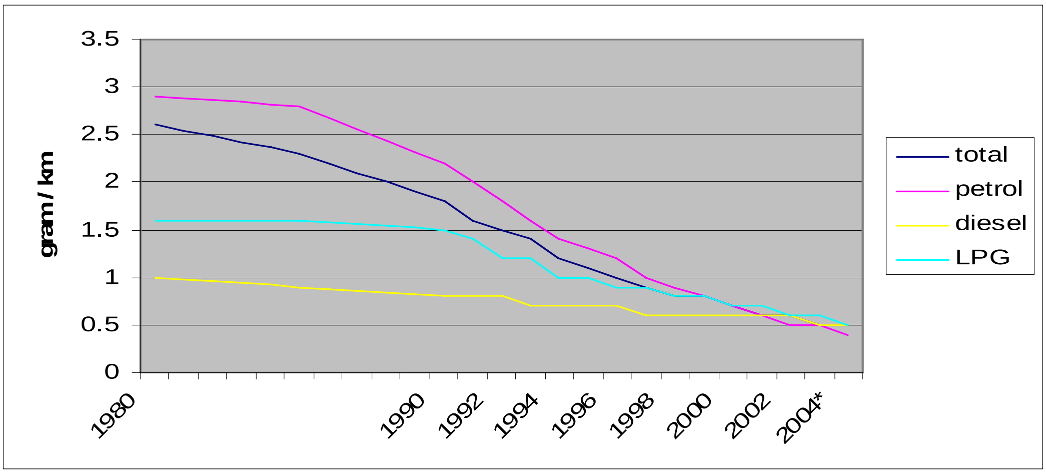
3.1 Introduction

Motorised transport and particularly passenger cars are responsible for substantial emissions of the greenhouse gas CO_2. Cars also contribute to local air pollution through emissions of NO_x and particulates[13], which may cause public health problems, and policies and technical measures to address car CO_2 emissions may also impact on the latter. In this chapter this topic is briefly introduced and some background given on the potential effect of CO_2 reduction measures on emissions of NO_x and PM_{10}.

3.2 Data

In the Netherlands the transport sector (excl. international aviation and maritime shipping) was responsible for 64% of aggregate NO_x emissions in 2002, with passenger cars alone accounting for 26% of the total figure (ECN/RIVM, 2005). The contribution of diesel cars to these emissions is projected to increase very rapidly. As can be seen in Figure 16, NO_x emissions from petrol cars have fallen steadily since catalytic converters were introduced in the late 1980s. While the NO_x emissions of new petrol cars are set to decline even further, this is not the case for diesel cars. In 2010 the average diesel car is expected to emit 8 times more NO_x per kilometre than the average petrol car. As a result of more stringent standards, total NO_x emissions of passenger cars and delivery vans are projected to decrease by 50% between 2002 and 2010. Nonetheless, it is not expected that the NEC[14] sectoral target of 158 kilotonnes will be achieved in 2010.

Figure 16 NO_x emission factors of the Dutch car fleet



Note: Figures for 2004 are provisional.
Source: (Statline, 2005).

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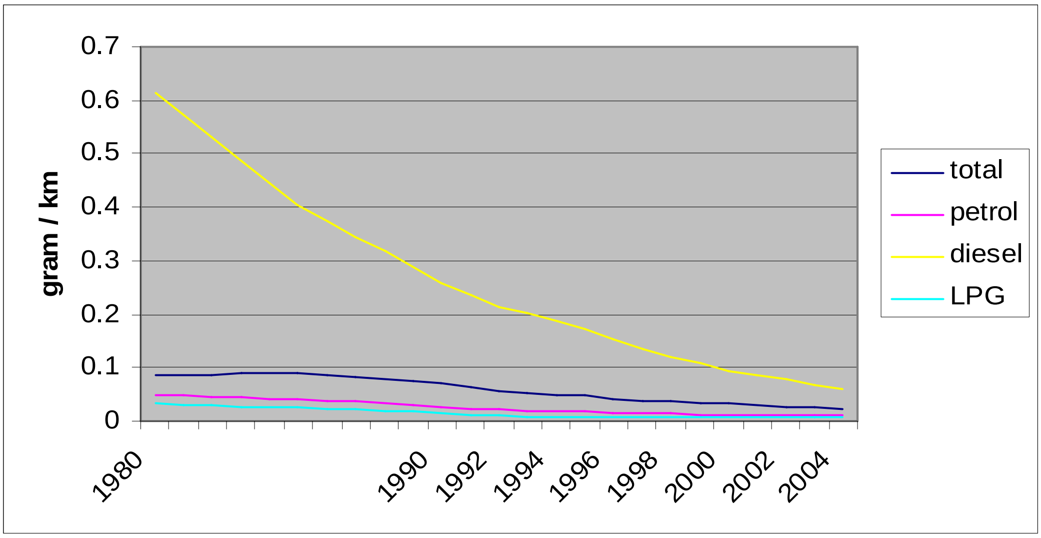
13 Particulate matter of different sizes, PM_{10} and $PM_{2.5}$.

14 National emission ceiling.

In 2002 the transport sector (excl. international aviation and maritime shipping) had a share of 35% in PM_{10} emissions in the Netherlands. About 40% of these transport emissions is due to passenger cars and delivery vans. Part of these emissions can be captured by particulate traps, or soot filters, and this measure is expected to reduce PM_{10} emissions in the coming years.

Figure 17 PM_{10} emission factors of the Dutch car fleet



Note: Figures for 2004 are provisional.
Source: (Statline, 2005).

3.3 Policy

Local air quality has become a hot topic in recent years. The European Commission's Clean Air For Europe (CAFE) programme has estimated that poor air quality was responsible for 370,000 premature deaths in the EU-15 in the year 2000. In the most polluted areas the loss in life expectancy may be up to two years[15]. This is due mainly to particulates and ground-level ozone. In the Netherlands a number of construction and development plans have been postponed because of their contribution to breaches of European air quality limits.

In assessing European policies on the CO_2 emissions of passenger cars, it is important to bear in mind how these relate to other policy objectives. At the European level, limits are imposed on the ambient concentrations of airborne particulates (PM_{10}, in effect since 2005) and nitrogen oxides (NO_x, in effect as of 2010). Although these substances can also damage human health at levels below these limits, all efforts are currently focused simply on compliance.

[15] For more details, see http://europa.eu.int/comm/environment/air/cafe/index.htm (consulted 4-11-2005).

When it comes to transport, the European standards for emissions from passenger cars (the ‘Euro standards’) have proven very effective and are the cause of the emissions reductions shown in Figure 16 and Figure 17. It is not only emissions per vehicle kilometre that have declined but also overall passenger car emissions, despite the growth in transport volumes[16].

3.4 Synergies and trade-offs

Policies aimed at reducing CO_2 emissions may also impact on air pollutant emissions, either negatively or positively.

In particular, air pollutant emissions are likely to increase if CO_2 emission reduction is achieved by means of a shift to diesel. Cars using diesel technology are more fuel-efficient than petrol cars, but emit more NO_x and particulates. Indeed, the current standards for diesel cars are less stringent in this respect. Thus, while a shift to diesel cars may be beneficial from the perspective of climate change, this is not presently the case in terms of local air quality. This is expected to change in the future, though, as diesel emission standards are to be tightened in 2009, when the Euro 5 standards come into force.

Concerns have recently also been voiced about the emissions of newer, more fuel-efficient petrol cars that have come onto the market. These have direct injection engines, which are more fuel-efficient than the indirect injection engines commonly used in the past. However, they emit $PM_{2.5}$, very small particles that are particularly damaging to human health. Particulate emissions from petrol cars are not yet regulated via the Euro standards.

However, not all policies or technical measures that improve the fuel efficiency of vehicles also have an impact on pollutant emissions. All new passenger cars must comply with the Euro standards currently in force, and engines are usually tuned in such a way that pollutant emissions levels just meet the standards (with a certain margin). Reducing vehicle weight or engine capacity or using a hybrid drive will therefore not have any significant impact on pollutant emissions, as it has on CO_2 emissions.

3.5 Conclusions

Passenger cars not only emit CO_2, but also contribute to local air pollution through emissions of NO_x and PM_{10}. When assessing measures to reduce car CO_2 emissions it is therefore important to bear in mind potential synergies or trade-offs with air quality objectives.

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[16] This trend is also observed in other European countries: between 1990 and 2002 emissions of acidifying substances, particulates and ozone precursors from transport as a whole fell by between 29% and 39% in the EEA member states (international aviation and maritime shipping excluded) (EEA, 2005).

In particular, emissions of air pollutants are likely to increase if CO_2 emission reduction is achieved by means of a shift to diesel. Although cars using diesel technology are more fuel-efficient than petrol cars, they emit more NO_x and particulates. This is expected to change in the future, as diesel cars come to comply with more stringent emission standards.

4 CO_2 mitigation policies

4.1 Introduction

As can be concluded from the data of Chapter 2, reducing passenger car CO_2 emissions is not something that will simply happen of its own accord. On the contrary, consumers today are opting for larger and more comfortable cars, leading to less fuel-efficient motoring than would otherwise have been the case. If there is to be any substantial reduction of CO_2 emissions, vehicle fuel efficiency needs to be further improved by car and engine manufacturers and consumers then need to buy these fuel-efficient cars. As a further step to reducing these emissions, fuels giving rise to lower CO_2 emissions than today's fuels can also be introduced. Biofuels are currently the best (and only) option here, as will be shown in the next chapter.

This chapter discusses government policies to bring about the required changes in the behaviour of both consumers and manufacturers. In the next section we first briefly analyse the reasons consumers opt for a specific car, and how car manufacturers decide on what cars to develop and offer their customers. Since policies aimed at reducing car CO_2 emissions will need to change the current preferences of both parties, it is necessary to understand these mechanisms if effective policies are to be developed. To an extent this section anticipates discussions later in the chapter, but it provides a concise framework within which these more detailed discussions can be better understood.

Section 4.3 briefly reviews the European as well as Dutch policies that are currently in place or may be developed in the future. Section 4.4 describes in more detail the current European policy context and Section 4.5 the policies presently implemented in the Netherlands. Section 4.6 looks at future developments. Based on the (inter)national literature, the potential impact of the various policies on CO_2 emissions is then described in Section 4.7. In Section 4.8 a number of conclusions are drawn.

4.2 How to influence consumer and car manufacturer choices?

What affects consumer choice of a new car?

Financial considerations obviously play a major role in consumers' choice of a new car, as do requirements as to number of passengers, safety aspects and so on. There is more to it, though. People are willing to spend more on their car than is necessary from an economic or practical perspective. Personal preferences play a role here and these are influenced to a large extent by the wider world. The types of car driven by the peer group, whether neighbours, work colleagues or business competitors, prove to be of key importance. And as with most other consumer choices, advertising campaigns by car manufactures are also effective in steering preferences.

How can these processes be steered and is there an economic motive for doing so?
One reason for government intervention is that the market for automotive fuel economy does not operate efficiently. Buyers of new cars generally only consider the first three years of fuel savings, and not the savings over the whole vehicle lifetime (NRC, 2002; Annema, 2001). As vehicle prices fall owing to new technologies or car manufacturing cost reductions, consumers may be encouraged to opt for larger and more comfortable vehicles, cancelling out potential CO_2 reductions. In addition, certain technological improvements are not implemented because potential benefits to consumers over the car's lifetime are only minor, while the risks for producers are high (Greene, 2005).

What kind of government measures are feasible?
We can distinguish between measures that aim primarily to influence:
a The supply side, i.e. the cars marketed by manufacturers, and
b The demand side, i.e. consumer choice.

Car manufacturers can be encouraged or even obliged to produce fuel-efficient cars. Present European efforts in this area are based on a voluntary agreement between manufacturers and the EU, with no obligations in place.

One long-standing policy measure is (differentiated) pricing policy. Many European countries levy taxes on car purchase (registration tax) or use (annual circulation tax and fuel taxes); see also Section 4.5. A consumer's choice for a particular model of car is obviously only made on purchase. Subsequently, it is only through fuel taxes that vehicle use and therefore environmental impact can be effectively controlled, with registration and circulation taxes no longer having any impact. Because the choice for a particular car is taken on purchase and most consumers do not compare annual operating costs in any detail, registration taxes may be more effective in influencing consumer choice than fuel and circulation taxes.

Another means of influencing consumer choice is by providing suitable information. Thus, fuel efficiency labelling has become mandatory in the EU, for example, the idea being that consumers will make a better informed (or more financially rational) choice as a result. They may opt for more fuel-efficient cars because this will lead to fuel savings and hence economic savings.

Is further technological improvement of fuel efficiency feasible?
Obviously, these policy measures can only be effective if fuel-efficient vehicle technology is indeed available and manufacturers are technically capable of supplying more fuel-efficient models of car.

Several studies have reported on technologies that might potentially be used to improve fuel efficiency and the general conclusion is that such improvements are technically feasible and indeed cost-effective from the perspective of society as a whole[17].

- IEEP/TNO/CAIR (2005) concludes that the 140 g CO_2/km target for 2008/09 actually brings cost benefits to society and net cost savings to the consumer.
- In a report for the British Department for Transport (Owen, 2003) the efficiency and costs of different measures for reducing carbon emissions from a mid-size diesel reference car were analysed. Based on the results, it can be concluded (Kågeson, 2005) that fuel economy improvements (by up to one third) are socio-economically cost-effective or close to it in the UK.
- According to (NRC, 2002) passenger car fuel economy could probably be increased by 12% (for subcompacts) to 27% (for large cars) and light truck fuel economy by 25% (small SUVs) to 42% (large SUVs), using technologies that would leave vehicle size, weight or performance unchanged.
- In the US the fuel economy of light-duty vehicles could be increased by 25-33% by 2015 using existing technologies that cost less than the value of the fuel saved (Greene and Schafer, 2003).

How can the government ensure that such improvements to new cars come about?
There are several policy options for this purpose, some of which are analysed in IEEP/TNO/CAIR (2005):

- Regulating the fuel efficiency of new cars is one possibility. This could be elaborated in one of several ways: per car (all cars must comply with e.g. 120 g CO_2/ km), per manufacturer (the average fuel consumption of all cars sold by the manufacturer must comply) or for the industry as a whole (the average car marketed must comply).
- Alternatively, individual manufacturers or the industry could be obliged to achieve a certain percentage improvement in fuel efficiency, with each manufacturer having to improve the average fuel efficiency of cars marketed by 30%, for example.
- A third option is to relate the required fuel efficiency to the utility of a car. For example, 'people carriers' or very luxurious cars would have to improve fuel efficiency by the same percentage as a small car.

Further labelling requirements (see Section 4.4.1) to make consumers more aware of lifetime vehicle costs (fuel costs and annual circulation taxes) may move consumers to opt for more fuel-efficient cars.

Does the lease car market operate differently?
Lease cars constitute about a quarter of all new cars sold in the Netherlands. This segment is generally relatively insensitive to price incentives. Although a comparatively high proportion of these cars run on diesel (or LPG), this share is not as high as might have been suspected based on the average mileage of 30,000 km.

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[17] This perspective does not take into account taxes, which are merely transfers in the economy from society's point of view, but does include the benefits of future fuel savings.

There are several reasons for this relative insensitivity to price. The person selecting the car is often not the person that has to pay for it. The choice of fuel therefore has little basis in financial considerations, with personal preferences (as mentioned earlier) often playing a more significant role than in the case of private cars. The costs of vehicle purchase and fuel represent only a relatively small fraction of a company's total budget, moreover, and employee satisfaction is deemed important, too. A third characteristic is that lease cars are typically replaced every two or three years, i.e. more often than private cars. Fuel efficiency improvements are therefore less cost-effective than if ownership lasted longer, so that the additional cost of more efficient vehicles must be recovered through fuel savings within a shorter time frame.

Specific policies targeting the lease market are discussed in Section 4.6.5.

4.3 An overview of policy measures

Both the Dutch government and the EU have already implemented a series of policy measures either aimed directly at reducing the CO_2 emissions of the transport sector or otherwise relevant to the topic. A number of new policies are being considered for the future, moreover.

Table 2 reviews both current and potential future policies. These will be discussed in the following sections.

Table 2 Current policies and incentives, and new developments most relevant for transport CO_2 emissions

Currently in place	Under development / new options
EU	
Voluntary agreements with car manufacturers (commonly known as the ACEA agreement)	Proposals on vehicle purchase and circulation tax
Labelling directive	Road pricing directive for goods transport
Biofuels directive	Possible new car policies after the ACEA agreement expires
In various EU member states, tax benefits and other incentives for biofuels	Transport may in future be included in the EU's greenhouse gas emission trading scheme (EU ETS)
	CO_2 compensation
The Netherlands	
Differentiated annual circulation taxes (according to vehicle weight and fuel)	CO_2 differentiation of passenger car registration tax
Differentiated registration taxes (according to vehicle price and fuel)	Road pricing
Fuel taxes	Future biofuels policies and goals
Tax benefits for hybrid and electric cars	CO_2 compensation
Labelling of new cars (A - F)	
Biofuels tax reduction in 2006, mandatory sales thereafter	
Subsidies for public transport	

Apart from these policies, it might be argued that government subsidisation of public transport also helps limit overall transport CO_2 emissions. In many cases, however, CO_2 emissions are not the main objective of these subsidies, for they also serve a social purpose (transport mobility for people unable to buy or drive a car) and contribute to the accessibility and appeal of densely populated areas.

4.4 EU policy

EU policy to reduce the CO_2 emissions of passenger cars aims to improve fuel efficiency and promote fuels with less CO_2 emissions. To improve fuel efficiency, three instruments are currently in place: voluntary agreements with car manufacturers, consumer information campaigns and market-oriented (fiscal) measures to influence consumer choice. These policies are discussed in Section 4.4.1. Section 4.4.2 discusses EU policy on the production and use of biofuels.

4.4.1 Improving fuel efficiency

The objective of the EU is to achieve, by 2010 at the latest, an average CO_2 emission figure of 120 g/km for all new passenger cars sold in the European Union[18] (average emissions in 2003 were 163 g/km). This target is to be secured by means of three instruments:

1. Voluntary agreements committing car manufacturers to reduce passenger car CO_2 emissions, mainly through improved vehicle technology.
2. Better consumer information on the fuel economy of cars.
3. Market-oriented measures to steer motorist choices towards more fuel-efficient cars.

The Commission informs the Council and European Parliament annually on the effectiveness of the strategy.

These three instruments will now be discussed in more detail, taking into account the latest communication by the Commission on the effectiveness of this strategy (COM (2005) 269 final).

Voluntary agreements

The European Commission has separate voluntary agreements (or self-commitments) with European (ACEA), Japanese (JAMA) and Korean (KAMA) car manufacturers. ACEA members have committed themselves collectively to achieving a CO_2 emission target of 140 g/km CO_2 by 2008. JAMA and KAMA are to secure this target by 2009. These targets are to be achieved mainly through technological innovations geared to a variety of car and engine characteristics and through market changes related to such developments.

If these targets are not achieved, the Commission intends to present a legislative proposal on CO_2 emissions from passenger cars.

[18] See http://europa.eu.int/comm/environment/co2/co2_home.htm.

In its most recent monitoring report (COM (2005) 269), the Commission notes that[19]:

- The sustained increase of the share of diesel vehicles in the EU market for new passenger cars has made an important contribution to the overall progress achieved so far.
- JAMA and ACEA can be considered to be on track, while KAMA's progress is unsatisfactory.
- Additional efforts are necessary to meet the final target of 140 g/km CO_2, as the average annual reduction rate of all three associations needs to be increased. It is noted that the gaps to be closed, expressed in required annual performance, are increasing.

Also included in these voluntary agreements was a 2003 review by the industry of the potential for additional CO_2 reduction, with a view to moving further towards the Community's objective of 120 g CO_2/km by 2012[20]. At the time, ACEA indicated that a further reduction of 5% (to about 133 g CO_2/km) might be feasible by means of improvements to vehicle technologies. According to ACEA and JAMA, going beyond this target would lead to prohibitive extra costs. The Commission responded by announcing an impact assessment, to be carried out during 2005. Based on the results, the Commission intends to put forward a proposal concerning achievement of the 120 g CO_2/km target around the end of 2005.

The Commission has also launched a tender procedure for development of a cost-effective measurement procedure for incorporating CO_2 emissions from mobile air-conditioning equipment. Air conditioning can increase fuel consumption by up to 10%, but the associated emissions are not currently incorporated in test cycles to assess the fuel efficiency of new cars.

Consumer information

The second instrument the EU has introduced to secure the 120 g CO_2/km target is provision of consumer information on the fuel economy and CO_2 emissions of newly marketed passenger cars. More in particular, Directive 1999/94/EC ensures that a fuel economy label is displayed at the point of sale. In addition, officially approved data on fuel consumption and specific CO_2 emissions must be included in all promotional literature for passenger cars.

When this directive was evaluated, the effectiveness of labelling was judged to be generally low, with no significant impact on consumer decisions discernible (ADAC, 2005).

19 Only excerpts from the conclusions are represented here; for the full text we refer readers to the original document.

20 Note that the EU policy documents relate the target of 120 g CO_2/km to the year 2010, while the voluntary commitments cite 2012.

Market-oriented measures

Market-oriented measures have been proposed to close the 20 g CO_2/km gap between the EU target for new passenger cars and the commitments made by the car manufacturers' associations. In 2005 the Commission presented a legislative proposal (COM(2005) 261 final) to link passenger car taxation to the fuel efficiency of the vehicle. The proposal is to restructure the tax base of registration (purchase) taxes and annual circulation taxes, basing these in full or in part on CO_2 emissions. More specifically, by 1 December 2008 at least 25% of the total revenue of these taxes should originate from the CO_2-based element. By the end of December 2010, this is to be at least 50%. The potential impact of this measure on CO_2 emissions is discussed in Section 4.7.

Note that in addition the Commission proposes to abolish registration taxes by 2016 at the latest, to improve the freedom of movement of cars in the internal market. This may actually increase the CO_2 emissions of (new) cars, as will also be discussed in Section 4.7.

4.4.2 Biofuels: promoting fuels with less CO_2 emissions

Another route to reducing the climate impact of passenger cars (or, rather, the road transport sector as a whole) is promotion of the use of biofuels. At the European level, Directive 2003/30/EC deals with the promotion of biofuels and other renewable fuels for transport. Under this directive, Member States must ensure that a minimum proportion of biofuels is placed on their markets and set national indicative standards to that effect. Reference values for these targets are 2% and 5.75% for 2005 and 2010, respectively[21]. Member States should consider the overall climate and environmental balance of the various types of bio-fuels and may give priority to promotion of those fuels showing the most cost-effective environmental balance.

In a separate directive, Member States were furthermore allowed to reduce the fuel tax on biofuels. Lowering fuel taxes is one sensible option for promoting the use of biofuels, as they cost more than fossil-based fuels. Several Member States have already taken such action to promote the use of biofuels.

All EU Member States have now set their own national targets and implemented policies for securing them (EC, 2005). There are many types of biofuels, but it is only biodiesel and bio-ethanol that play any role in the current EU market. Output of these biofuels is growing rapidly: in the period 2003-2004 biodiesel production in the EU-25 increased by 29% and bio-ethanol production by 16%. Despite these developments, though, the non-binding EU target of 2% for 2005 is expected to be achieved in Germany only.

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21 Calculated on the basis of energy content of all petrol and diesel marketed for transport purposes.

4.5 Dutch national policy

Many of the policy measures in the Netherlands stem from requirements of the European Commission. These requirements were discussed in the previous section and will not be discussed further in any detail here. In this section we briefly describe the Dutch policy context, examining the car and fuel tax system (4.5.1), specific measures to improve passenger car fuel efficiency (4.5.2) and the promotion of fuels having less CO_2 emissions (4.5.3). The current car and fuel tax system is discussed separately, because it was originally conceived not in terms of climate policy but rather as a source of government revenue.

4.5.1 Current system of car and fuel taxes

In the Netherlands there are four different taxes of relevance to passenger car purchase and use:
- Registration tax.
- Annual circulation tax.
- Fuel tax.
- Value Added Tax (VAT).

Vehicle registration tax (known by the Dutch acronym BPM) is levied on purchase of a new vehicle, the tax being indexed to the vehicle's net list (catalogue) price with a certain figure added or deducted depending on engine type. The BPM to be paid is calculated as 45.2% of the tax base. Diesel cars pay a surcharge of € 844.56 (45.2% of € 1,540 + € 328).

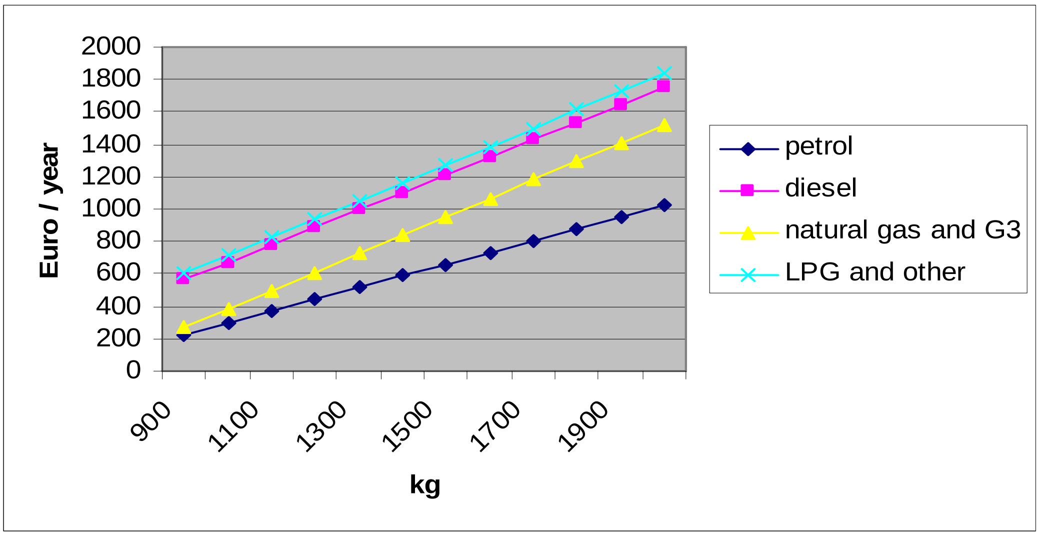
Table 3 Registration taxes in the Netherlands

	Tax base	Tax rate
Passenger car or delivery van (no diesel engine)	List price - € 1,540	45.2% of tax base
Passenger car or delivery van (diesel engine)	List price + € 328	45.2% of tax base

Source: (Belastingdienst, 2005a).

Annual circulation tax in the Netherlands (known by the acronym MRB) is indexed to vehicle weight and fuel type. The tax differs according to the province where the owner lives, but these differences are relatively minor. Vehicles that are 100% electrically powered are exempted (Belastingdienst, 2005b), as are cars over 25 years' old. As an illustration, Figure 18 reviews tax rates in the province of Utrecht for several weight classes and fuel types. The tax structure encourages use of petrol-fuelled and light-weight cars.

Figure 18 Annual circulation taxes in the Dutch province of Utrecht in 2005, by vehicle weight



Source: Based on calculation program on http://www.belastingdienst.nl/mrb/mrb-10.html.
NB. G3 is an LPG car with a certified G3 equipment, with low pollutant emissions.

In the Netherlands fuel excise duty is also differentiated according to fuel type. The rates in force in August 2005 are given in Table 4.

Table 4 Fuel excise duty in the Netherlands, August 2005

	Petrol (Euro-Super 95)	Diesel	LPG
Duty (Eurocent / litre)	66.49	38.04	5.46

Source: Oil Bulletin (2005).

VAT is also levied on newly purchased passenger cars as well as on fuel. The Dutch VAT rate is 19%.

Clearly, it is relatively expensive to purchase a diesel car, as it is to own one. The fuel tax is comparatively low, however. Similar incentives are in place for LPG cars: owning one is very expensive, but driving it is cheap. Diesel and LPG are therefore attractive for motorists with a relatively high annual mileage.

One motive for the relatively low diesel excise duty is to ease the tax and thus overall cost burden on commercial hauliers. To offset the incentive resulting from this low excise duty, registration and circulation taxes on diesel passenger cars are set relatively high. This system thus maintains government revenues while limiting the share of diesel in the car fleet (for air quality reasons).

4.5.2 Improving fuel efficiency

Specific policies are in place in the Netherlands to improve the fuel efficiency of passenger cars through a combination of consumer information and tax incentives.

In line with the labelling currently required by the European Commission, fuel efficiency classes (A-G) were introduced in the Netherlands in 2001. However, the Dutch system deviates somewhat from that in most other EU countries, with labels indicating a car's fuel efficiency relative to cars of about the same size. A (green) A label, for example, means that a car is over 20% more fuel-efficient than the average car of that size, a (red) G label that it is over 30% less efficient than average. The reason this system was adopted rather than one based on absolute CO_2 emissions is the notion that car buyers go to the dealers with a well-defined wish list as to the car's main characteristics, such as comfort, size and model. The fuel efficiency of selected models is then compared with that of cars more or less similar with respect to these characteristics. Consumers looking for an MPV will therefore not be incentivised to buy a mid-range car, but may be moved to opt for a relatively fuel-efficient MPV.

Under a (temporary) regulation introduced in 2002, refunds of € 1,000 and € 500 were given on the registration tax of vehicles labelled A or B (the two most energy-efficient classes). This proved to be very effective, with purchases of these cars rising sharply. The share of newly sold class A cars rose from 0.3% to 3.2% in 2002. For class B cars an increase from 9.5% to 16.1% was observed. The refund was abolished, however, after which the percentages of class A and B cars sold declined once more.

In its budget for 2006 the Dutch government announced that from July 2006 onwards passenger car registration tax would be made part-dependent on CO_2 emissions (Financiën, 2005). The rebates and fees on top of current registration taxes will be made dependent on the energy efficiency class of the car. Cars in classes A and B will receive a rebate of € 1,000 and € 500, respectively. Cars in classes D, E, F and G will have to pay an additional fee of € 135, € 270, € 405 and € 540, respectively. Note that in this system rebates and additional fees do not correlate directly with fuel efficiency, because of the system of energy labelling explained above. It may, for example, be the case that an additional fee has to be paid for a small car with a relatively high fuel efficiency, while a rebate is given for a larger, less fuel-efficient car. The environmental effect of this measure is estimated to be 100 ktonne CO_2 emission reduction in 2011.

Table 5 Rebates/surcharges on vehicle registration tax in the Netherlands (per car), current situation and as proposed in the Dutch government's 2006 budget

Rebates/surcharges on registration tax (per car)		Fuel efficiency class						
		A	B	C	D	E	F	G
Current situation, until 1-1-2006								
	Hybrid	- € 9,000	x	x	x	x	x	x
	Non-hybrid	x	x	x	x	x	x	x
1-1-2006 until 1-7-2006								
	Hybrid	- € 9,000	- € 3,000	x	x	x	x	x
	Non-hybrid	x	x	x	x	x	x	x
From 1-7-2006								
	Hybrid	- € 6,000	- € 3,000	x	€ 135	€ 270	€ 405	€ 540
	Non-hybrid	- € 1,000	- € 500	x	€ 135	€ 270	€ 405	€ 540

Source: Memorie van Toelichting Belastingplan (2006), Ministerie van Financiën (2005).

On top of the differentiation for regular passenger cars, Table 5 shows that a special rebate system is in place for hybrid vehicles. Hybrids with energy efficiency label A are currently exempted from registration tax. This system will change in the coming year, with hybrids labelled A receiving a rebate of € 6,000 (from July 2006 onwards), those labelled B a rebate of € 3,000 (from January 2006). Hybrids with other energy efficiency labels are treated as non-hybrids and for these the same additional fee must be paid.

It is currently unclear to what extent this differentiated system is in line with the EU proposal. The proposal reads that differentiation should be based on 'the amount in grams of carbon dioxide emitted per kilometre by each particular car'. Whether further subdivision into different types of vehicle is permitted is unclear.

4.5.3 Biofuels: promoting fuels with less CO_2 emissions

With respect to the promotion of biofuels, Dutch policy aims for a 2% share in road transport fuels in 2006. Two different tracks are distinguished in the biofuels policy outlined in the 2006 budget.

- Under the general track, blending of up to 2% of biofuels in petrol and diesel is stimulated by a rebate on excise duties in 2006. From 2007 onwards, oil companies will be obliged by law to sell biofuels, namely 2% of their total road transport fuel sales. Note that the excise rebate is only a temporary measure, giving the government time to implement the desired legislation to make sale of biofuels obligatory.
- Under the innovative track, subsidies will be provided to promote development and use of new biofuels, which in the longer term are expected to take over the market entirely (see Section 5.5.2).

At the time of writing these policies are to be further developed, in the coming months, with details as yet known.

In addition, there are various subsidy schemes in place in the Netherlands aimed at promoting R&D on sustainable biofuel technology. Examples include the GAVE[22] programme and the UKR[23] scheme, which is part of the country's Energy Transition programme.

4.6 Future policy developments

In this section potential future policies to further limit the CO_2 emissions from passenger cars are discussed. Currently, the main pillar of EU policy on CO_2 reduction in cars are the voluntary agreements with car manufacturers. Although these have proven effective and average fuel efficiency has improved, it is as yet unclear whether policy targets (140 g/km in 2008, 120 g/km in 2010) will be achieved. The main policy driver with regard to CO_2 emission reductions via fuels is the EU biofuels directive, which has led to far greater biofuel incentives (and biofuel use) in EU Member States. In the Netherlands labelling is in place, while CO_2 differentiation of registration tax and biofuel incentives are planned to be introduced next year.

Clearly, further development of these policies is anticipated in the future and new policies may be introduced. There are several alternative and/or additional instruments that may be employed in the future, namely:

- Regulatory standards (section 4.6.1).
- Road pricing and fuel taxes (4.6.2).
- Emission trading and compensation (4.6.3).
- Further labelling requirements (4.6.4).

Note that some of these measures can be combined. For example, regulatory standards can be set for the CO_2 emissions of new cars while manufacturers are allowed to trade CO_2 emission credits (see below). Specific policies targeting the lease market are discussed in Section 4.6.5.

4.6.1 Regulatory standards

We first briefly discuss three forms of regulatory standards. Each has its own particular advantages and drawbacks (in terms of costs to manufacturers and consumers, for example), which will not be discussed in detail here[24].

Regulating top speeds, cylinder capacity, engine power or maximum fuel consumption

CO_2 emissions can be regulated in a variety of ways, for example by imposing limits on the emissions per kW engine power or engine volume, by regulating the permissible top speed, or by regulating emissions per kilometre. As Kågeson (2005) points out, for any given model of car, any increase in potential power output that raises the top speed by 10 km/h results in a real increase in fuel

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[22] GAVE stands for Climate Neutral Gaseous and Liquid Energy Carriers. GAVE actively supports the government and relevant market parties in their efforts within the framework of the EU Biofuels Guideline.

[23] UKR stands for 'Unieke Kansen Regeling' (Unique Opportunities Programme).

[24] See Kågeson (2005) for further information on this topic).

consumption of 0.4-0.7 litres/100 km on urban roads and 0.2-0.3 litres/100 km on motorways. Some of these regulatory measures can be expected to have negative side-effects. For example, relating CO_2 emissions to vehicle weight might prove counter-productive, as manufacturers might respond by increasing vehicle weight to make room for more engine power.

Regulating average emissions via corporate sales figures
In the US minimum standards for fuel economy are in force that must be complied with by the average vehicle sold by each manufacturer. One problem with this system is that it provides hardly any incentive for manufacturers geared to producing small vehicles, while producers of on average larger cars may face very tough restrictions.

Tradable CO_2 emission permits for new registrations
The idea of a combined regulatory and trading regime for manufacturers has been floated for over a decade now. The basic idea is simple: the Commission would set a cap on average emissions per new car sold of, say, 120 g CO_2/km in 2010. Manufacturers selling cars with better fuel economy receive credits, say one for each gram emission prevented. These credits can be used by the same manufacturer to sell cars emitting more, but can also be traded with other manufacturers, who can then in turn sell cars with a poorer fuel economy than the cap. This system is expected to be introduced in California next year.

The main advantage of this kind of regulatory system is that the agreed target is indeed reached. It should be born in mind, though, that the measure only regulates the fuel economy of new cars, not their actual use. Ultimate CO_2 emissions are therefore only partly regulated.

4.6.2 Road pricing and fuel taxes

As explained above, another means by which CO_2 emissions from passenger cars can be curbed is through road pricing and/or fuel taxes. In general, car owners face two types of cost: variable costs that vary with actual car usage, such as fuel costs and motorway tolls, and fixed costs that are independent of annual mileage, such as registration and circulation taxes.

There is a wide body of evidence indicating that car *use* depends chiefly on variable rather than fixed costs[25]. By increasing the variable costs to users (by introducing road pricing or raising fuel taxes, for example), policy-makers could thus influence car use. There are several sound motives for doing so, the main one being to internalise external costs. At the moment the variable charges paid by car owners are below the optimum from a societal point of view, as they do not reflect the external effects of car use, in particular environmental impact costs, external accident costs and variable infrastructure costs (CE, 2004). This is especially true of diesel cars, which pay relatively little duty on fuel. Overall car

[25] On the other hand, the type of car purchased may very well be governed more by incentives at the time of purchase, such as registration tax.

use thus exceeds the socially desirable optimum. This could be remedied by internalising the various external costs by adjusting variable user charges[26].

This could be implemented in a variety of ways, for example through congestion pricing (e.g. rush-hour tolls on congested roads) to internalise external congestion costs, or by varying road pricing according to vehicle emissions. Indeed, this would be in line with the polluter pays principle. Optimally, account would be taken not only of the *level* of external effects, but also of their *structure*. It is not so much car use that one would want to limit, but the negative side-effects on society as a whole. By taking account of the structure of external effects, drivers would not only be incentivised to drive less, but would also be steered towards more environmentally friendly cars and fuels.

In many countries passenger cars are subject to road pricing in the form of motorway tolls. Tolls may be a good instrument for internalising the variable costs of road use (maintenance) and possibly for refinancing infrastructure. Tolls may also reduce CO_2 emissions, as they increase the variable costs of driving. This effect could be enhanced by differentiating tariffs according to the fuel efficiency of a car. Nowhere has this has yet been done, however.

A more sophisticated form of road pricing, whereby vehicles pay a fixed tariff for each kilometre driven, has thus far been introduced in several European countries for heavy-duty vehicles, and many studies have been carried out on the effectiveness of this kind of policy. Depending on charge levels, road pricing can be an effective means of reducing the negative impact of transport.

Until now, the costs of such a system have proven prohibitively large to introduce sophisticated systems of road pricing for passenger cars. Simpler forms can be effective in curbing congestion and transport levels and may be just as cost-effective from a social point of view in reducing transport CO_2 emissions. One option may be to introduce tolls on specific (stretches of) roads.

Fuel taxes can only be used to internalise the external costs of CO_2 emissions, for it is only a car's CO_2 emissions that are directly related to fuel type and consumption. Road pricing has the advantage that it can simultaneously be used to internalise the costs of other external effects like air pollution and congestion.

4.6.3 Emission trading and compensation

The European Emission Trading System, or EU ETS, came into force on 1 January, 2005. Its direct purpose is to reduce greenhouse gas emissions, building on the so-called flexible mechanisms developed under the Kyoto Protocol. Under an emission trading scheme, polluters require a permit to emit. These permits can be traded, such that emission reductions take place where they are cheapest. The EU ETS should allow the EU to secure its Kyoto target at a cost of between € 2.9 and € 3.7 billion annually (EC, 2004).

[26] Note that basing fixed car taxes on CO_2 emissions is also a means of internalising external effects.

At this initial stage the EU ETS covers only stationary sources that count as 'large emitters', and these are allocated allowances which can then be traded. Although the transport sector is not included in the EU ETS, the emissions of this sector are included in Member States' Kyoto targets[27]. Member States are thus held responsible for transport sector emissions and any growth of these emissions will have implications for other sectors.

The European Union has taken responsibility for the greenhouse gas emissions[28] (GHG) on its territory. Under the UNFCCC process, the EU is committed itself to reducing its GHG emissions by 5.2% below 1990 levels during the period from 2008 to 2012. Now the Kyoto Protocol has been ratified, this commitment is legally binding. Under the agreement there are three 'flexible mechanisms' to ensure emission reductions are taken in the most cost-effective manner. In each case emissions in one place are compensated elsewhere.

In the first case there is emissions trading itself. Emission rights can be traded so that reduction measures are taken, in principle, where costs are least. Emitters facing higher abatement costs can purchase credits from other emitters that can implement reduction measures at relatively low cost. The other two flexible mechanisms are Joint Implementation (JI) and the Clean Development Mechanism (CDM). These allow industrialised countries to achieve part of their reduction commitments by implementing emission-reducing projects abroad and counting the achieved reductions as part of their own commitment. JI allows projects in other industrialised countries with Kyoto targets, while CDM takes place in countries without such targets (i.e. developing countries). Credits for the reductions achieved are conditional on the projects resulting in real, measurable and long-term climate change benefits. There are limits on the use of JI and CDM: use of flexible mechanisms should be complementary to domestic efforts.

The EU ETS also allows for use of JI and CDM, although it excludes use of so-called carbon sinks, for the reason that these are inherently temporary and reversible.

There are also several compensation-type schemes at the consumer level[29], whereby CO_2 emissions are offset by the planting of trees. After a while these trees will die, however, and release most of the CO_2 captured during growth, with only a small fraction remaining in soils and the deep ocean as a result of biolo gical processes. For these schemes it is therefore important that the areas where trees are planted remain designated as forest indefinitely; If not, compensation will be ineffective in the longer term.

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27 An exception should be made for emissions from international aviation and maritime transport.

28 There are six types of greenhouse gas: CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

29 Examples are 'Trees for Travel', directed at compensation of emissions from air transport, and the VISA Green Card. VISA compensates for the emissions associated with purchases paid for by this credit card.

4.6.4 Further labelling requirements

EU policy also seeks to reduce CO_2 emissions from passenger cars by influencing consumer choice; see Section 4.4.1. This has been implemented in the Netherlands, as discussed in Section 4.5.2. As has become apparent, though, consumers do not always take account of the costs of a vehicle over its full lifetime (or the time they themselves drive it). One way to make consumers more aware of additional costs like annual circulation taxes and fuel costs would be to inform them of these costs at the time of vehicle purchase. Apart from listing fuel efficiency, illustrative calculations could be presented to make consumers aware of the annual financial impact of fuel efficiency and circulation taxes.

4.6.5 Dedicated policy for the lease market

As noted above, lease cars occupy a special position in the passenger car market. In the Netherlands they account for 25% of new car sales. With these cars purchasing decisions do not take full account of fuel efficiency, as the person choosing the car is not paying for it. The vehicles are resold after only two or three years, moreover, so the company leasing the car (and thus paying the additional costs of fuel-efficient technology) will benefit only from a small fraction of overall fuel efficiency gains. For these reasons it may be a good idea to target this sector with specific measures. Below we briefly discuss one such measure, introduced in the UK in 2002, thereby basing ourselves on (Inland Revenue, 2004).

In 2002 the British company car tax regime was reformed. In the UK companies account for about 50% of all new car purchases each year (including cars not intended for private use, such as rental vehicles and taxis). Under the old regime, the company car tax was based on the list price of the car and the annual business mileage by the company car driver. In general, the taxable value of the car benefit was calculated as:

- 35% of the list price if less than 2,500 business miles were driven annually.
- 25% if driving 2,500 to 17,999 business miles.
- 15% if driving 18,000 or more business miles.

Company drivers thus had an incentive to drive 18,000 miles annually.

The new company car tax system is based on the amount of CO_2 emitted per kilometre. The minimum percentage applied is still 15%. In 2002/3 this percentage of the list price was taken as taxable value if the CO_2 emissions were 165 g/km or less. This lower threshold is adjusted annually and will be set at 140 g/km in 2005/6. For each additional 5 g/km above the lower threshold, the percentage increases by 1%. Furthermore, diesel cars not meeting Euro IV standards incur an additional charge of 3% and cars running on alternative fuels qualify for discounts.

The new tax regime is designed to provide financial incentives for employers and company car drivers to choose cars which produce lower levels of CO_2 emissions. It also aims to encourage car manufactures to develop and introduce greener cars. One-off costs of the new regime to employers were estimated at 55 million pounds, the year-on-year reduction in recurring compliance costs at 35 million pounds.

The impact of the reform is estimated as follows:

- Saving of 0.15-0.2 Mtonne CO_2 emissions in 2003 alone (equivalent to 0.5% of the CO_2 emissions from all road transport in the UK)[30].
- Elimination of the incentive for unnecessary car use for tax purposes, reducing business travel by an estimated 300-400 million miles (480-640 mln km) in 2003.
- Among employers, 36% stated they had changed their policy towards car list prices.

Clearly, targeting this particular market segment can have a substantial impact on the fuel efficiency of a country's car fleet.

4.7 Effect of pricing policies

As outlined in the previous sections, various types of fiscal policies can be implemented to promote fuel-efficient cars. A number of studies have been carried out to estimate their effectiveness and some of the results are presented below.

In 2001 RIVM/MuConsult published a study on the effectiveness of different pricing policies in the Netherlands. The three pricing options considered were:

- Differentiation in registration tax on new cars based on a system in line with the energy efficiency labelling.
- Annual circulation tax based on fuel use instead of vehicle weight.
- A premium for owners of new cars with a green energy label.

They concluded that basing the circulation tax on fuel consumption rather than weight would have no effect. This would have only a minor impact on circulation taxes, as the two parameters are fairly strongly interrelated. In contrast, differentiating the registration tax and providing a premium for new cars with a green
energy label would be more effective (see also Section 4.5.2 for specific results on refunds on registration taxes). A premium might be more effective than differentiating the circulation tax, as it would be more visible to the consumer. Higher premiums and differentials would be more effective than relatively low premiums. In either case, however, the supply-side responses of car dealers are anticipated to dampen the potential impact, as they are expected to adjust car prices in reaction to both premiums and differentials.

There is further evidence that differentiating the registration tax has a greater impact than equally burdensome differentiation of the annual circulation tax (cf. Kågeson, 2005). The rationale is that car buyers will only take account of the

[30] And, according to (Inland revenue, 2004), on course to meet the originally anticipated reduction of between 0.1 and 1 Mtonne annually in the long run.

incentive provided by the annual circulation tax for a few years and not for the impact of this differentiation over the entire vehicle lifetime. Also, the first buyers of new cars do not expect to be able to pass on all of the (remaining) registration tax to the second owners.

In 2002 a study commissioned by the European Union's DG Environment was published on the potential of fiscal measures for CO_2 reduction of new passenger cars (COWI, 2002). In it, inclusion of a CO_2 element in the tax base of existing taxes is estimated to have potentially significant impacts. For the Netherlands, reforming registration and circulation taxes such as to make them fully dependent on a car's CO_2 emissions, while keeping total revenues from these taxes unchanged, could reduce CO_2 emissions by up to 7%.

The influence of registration and circulation taxes was also analysed by CE (2001) in a study comparing the tax systems and car fleet characteristics in eight European countries. The results showed, among other things, that:

- High registration taxes reduce the size of the car fleet and average car mileage, but not the total mileage driven.
- In countries with high registration taxes, the average weight and engine capacity of cars (both related to fuel efficiency) are less than in other countries.
- Differentiation of circulation taxes can influence the average weight and/or engine power of the cars sold.
- Higher fuel excise duties correlate with less mileage, higher occupancy rate and smaller engine capacity.

From the perspective of reducing passenger car CO_2 emissions, abolition of registration taxes (as proposed by the European Commission) may therefore not be the best policy option.

It is often said that fuel taxes have no impact on fuel consumption and CO_2 emissions. This is contradicted by the empirical evidence, however, for throughout the last 30 years regions with relatively low-priced fuel score low on car fuel economy (US, Canada, Australia) while those with relatively high-priced fuel (due to fuel taxes) score better (Japan, European countries). For example, fuel taxes are about 8 times higher in the UK than in the US, resulting in fuel prices that are about three times higher. UK vehicles are about twice as fuel-efficient, mileage is about 20% lower and vehicle ownership is also lower. Clearly, car usage is sensitive to price (VTPI, 2005).

The long-run impact of fuel price increases on fuel consumption are typically about 2 to 3 times greater than the short-run impact (VTPI, 2005). People have many more ways of responding in the long run (by buying a more fuel-efficient car, for example, or moving house or changing job to reduce commuter travel, etc.). (Goodwin, Dargay and Hanly, 2003) have reviewed international studies on the impact of price changes, i.e. the so-called price elasticities, in both the short and long run. The impacts of a permanent increase in the real price of fuel are shown in Table 6.

Table 6 Impact of a permanent increase in real fuel prices by 10%

	Short run (within 1 year)	Long run (5 years)
Traffic volume	-1%	-3%
Fuel consumption	-2.5%	-6%
Vehicle fuel efficiency	-1.5%	-4%
Vehicle ownership	Less than -1%	-2.5%

Source: Goodwin, Dargay and Hanly (2003).

4.8 Conclusions

There are many national and international policies in place that could be used to incentivise improvements to the fuel efficiency of new cars. Nonetheless, a number of studies indicate that technical measures that cost less than the fuel savings over a vehicle's lifetime are still not being implemented. Clearly, the market for fuel efficiency is not working as efficiently as it might or should, even though car usage proves sensitive to pricing. Future policy should be geared to ensuring that fuel efficiency improvements that are beneficial from a socio-economic perspective are indeed implemented.

Regulatory standards and emissions trading are among the additional policy measures that might be introduced. Regulatory standards can be applied in differing degrees of flexibility. A single standard might be set for all cars: a limit of 120 CO_2 g/km, say. Alternatively, and more realistically, standards could be made tradable, for example, allowing manufacturers that do better than required to sell credits to those who do worse.

One market segment that can be addressed more specifically is the lease market, which accounts for a quarter of new car sales in the Netherlands. Many of these vehicles will come onto the second-hand market within four years of purchase. At present their fuel efficiency is not adequately taken into account at the time of purchase, as the person choosing the vehicle is not generally paying for it. The tax regime could be adjusted such that all parties are incentivised to opt for fuel-efficient models.

Compensation of emissions by tree-planting is a delicate issue, as only a small fraction of the CO_2 initially captured will remain trapped in soils and deep seas through biological processes. If compensation is to be successful, it is essential that areas where trees are planted remain designated as forest indefinitely. If not, this form of compensation will be ineffective in the longer term.

5 CO_2 reduction potential

5.1 Introduction

As explained briefly in Section 1.2, there are three basic ways of limiting car CO_2 emissions:
- By limiting the growth of the number of kilometres driven.
- By improving vehicle energy efficiency (i.e. fuel efficiency).
- By using fuels that give rise to lower CO_2 emissions.

Scenario studies such as (RIVM, 2003b) conclude that all three options will be necessary to achieve significant CO_2 emissions reductions in the transport sector in the future. Since CO_2-neutral energy is expected to be scarce in the future, too, fuel-efficient cars will be needed to utilise the available energy as efficiently and cost-effectively as possible.

In the following sections the two latter options will be explored[31]. First, the various vehicle technologies and available fuels are briefly reviewed, and the methodology used to compare options is briefly explained. The fuel economy of a number of car/fuel combinations is then discussed and the potential for further improvements analysed. A more detailed technical explanation of the various vehicle and fuel technologies can be found in Annex A.

5.2 Vehicle and fuel technologies

5.2.1 Vehicle technologies

Car dealers currently offer a very wide range of models and engine technologies, with an equally wide range of CO_2 emissions per kilometre. In general terms the range of cars on offer now or in the future includes:
- Conventional diesel and petrol cars.
- LPG cars.
- CNG cars.
- Electrical cars.
- Hybrid cars.
- Flex-fuel cars (cars that can run on ethanol and petrol blends in varying percentages, up to 85% ethanol[32]).
- Small and large cars (e.g. a Smart versus an SUV).

In the future, hydrogen cars (possibly using fuel cells instead of an internal combustion engine) may also come onto the market.

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[31] Reducing the number of kilometres driven is not within the scope of this project.

[32] These cars have conventional (petrol) engines, but with an improved engine management system that can detect the ethanol content and adjust engine management accordingly.

These various categories of car differ in their fuel economy and consequently CO_2 emissions per kilometre. For example:

- The CO_2 emission factors of hybrid cars are much lower than those of comparable conventional cars.
- Smaller cars and/or cars with less engine power are far more fuel-efficient than large cars with more powerful engines.
- Diesel cars have lower fuel consumption than petrol cars.
- The CO_2 emissions of electric cars, while zero on the road, occur further back up the chain, during power generation, and are therefore governed by the type of electricity used to charge the batteries.
- Likewise, the CO_2 emissions of hydrogen cars depend on how the hydrogen is produced.
- The CO_2 emissions of flex-fuel cars depend on the percentage of ethanol used, and the greenhouse gas reduced with the ethanol (this depends on the biomass used for biofuel production, for example, as will be explained in Section 5.4.4).

5.2.2 Fuel technologies

There are likewise a variety of motor fuels, of energy carriers, of both fossil and biological origin:

- Petrol.
- Diesel.
- LPG (liquefied petroleum gas).
- CNG (compressed natural gas).
- Electricity.
- Currently available biofuels: biodiesel[33], pure plant oil, bio-ethanol and ETBE (ethyl tertiary butyl ether, a petrol additive).
- 2nd generation biofuels: bio-ethanol from woody biomass, Fischer Tropsch diesel from biomass[34] and HTU (hydrothermal upgraded) diesel.
- Hydrogen.

As mentioned above, hydrogen may also prove to be a feasible alternative in the future. Furthermore, so-called 2nd generation biofuels are currently being developed, such as Fischer-Tropsch diesel (also known as biomass-to-liquid, BTL), HTU diesel and ethanol from woody biomass. These biofuels are expected to perform much better than the current generation in terms of both environmental impact and cost[35]. We expect that at least some of the 2nd generation biofuels can be produced on a significant scale within about 10 years, which means they could play an important role in the long-term vision of sustainable mobility (in tandem with very fuel-efficient cars).

33 In this report we use the term biodiesel for Fatty Acid Methyl Esters, often referred to as FAME. FAME is not the same as pure plant oil, sometimes also referred to as biodiesel. Both can be produced from vegetable oil, but the latter is chemically unmodified.

34 This is diesel fuel produced from biomass using a very different process from that used to produce the biodiesel just mentioned.

35 See, for example*, Biofuels under development, an analysis of currently available and future biofuels, and a comparison with biomass application in other sectors*, Kampman et al., CE Delft, 2005.

5.2.3 Car / fuel combinations

Combining car technologies and fuels, a variety of realistic (either now or in the future) car technology/fuel combinations can be identified. These are shown in Table 7. Each combination has different emission characteristics for CO_2 and air pollutants, as well as different costs.

Table 7 Realistic car/fuel options, either currently available (c) or expected to be available in the future (f)

Car technology/fuel	Petrol	Diesel	LPG	CNG	Electricity	1st Generation biofuels[a]	2nd Generation biofuels[a]	Hydrogen
Conventional cars	c	c				c[b]	f	
Hybrid cars	c	c				c[b]		
LPG cars			c					
CNG cars				c				
Electrical cars					c			
Flex-fuel cars	c					c	f	
Hydrogen cars								f

[a] We shall distinguish the various biofuels cited in the list above.
[b] Current conventional and hybrid cars can only run on bio-ethanol/petrol or biodiesel/diesel blends with a limited percentage of biofuel.

Some of the fuels are directly linked to a specific car technology (e.g. CNG can only be used in CNG cars), while others are more wider applicable (e.g. bio-ethanol can be used in petrol cars, in hybrids and, in the future, possibly also in fuel-cell cars). The CO_2 emissions per kilometre of a specific fuel will therefore depend not only on the fuel but also on the car technology used: the fuel efficiency of the vehicle will be an important parameter for the result. Quantification of the environmental performance of fuels on a per-kilometre basis must therefore relate to a specific model and technology.

5.3 Some methodological issues

To enable fair comparison between current and alternative fuels, their respective environmental impact needs to be estimated over the entire life cycle of the fuel (using life cycle analysis, LCA). This means that for electricity and hydrogen, power generation and hydrogen production must be included. For fossil fuels, the emissions associated with production, transport and refining should be included, as well as combustion emissions.

In the case of biofuels, the CO_2 emissions from fuel combustion are equal to the amount of CO_2 taken up by the biomass during cultivation. On top of these come emissions occurring during crop cultivation as well as during the biofuel production process, though, and these must also be taken into account. If biomass residues are used for biofuel production, the LCA will have to duly account for the alternative use of these residues. For example, if sugar beet residues are used for biofuel production that would otherwise be used as cattle fodder, additional fodder (such as soy beans) will need to be cultivated, and the emissions associated with the soy beans should therefore be allocated to biofuel production. A more detailed explanation of biofuels LCA methodology can be found in (CE, 2005), for example.

Greenhouse gas emissions thus vary across biofuels. In fact, there may be major variations between batches of the same biofuel, as emissions will depend on the biomass used as a feedstock and the details of its cultivation, during which fertiliser use may cause very significant emissions of the greenhouse gas N_2O.

Another methodological issue that needs to be mentioned here is that there are (at least) two ways to analyse and compare CO_2 emissions:

- By measuring fuel efficiency during a standard test drive cycle, as defined by the European Union.
- By measuring fuel efficiency under real-life driving conditions.

These two measurement options will lead to different results.

The first method is used as a basis for European and Dutch policies, such as labelling, the ACEA agreement and the (proposed) tax incentives. The second yields more realistic data about real-life CO_2 emissions and is used for emission inventories, as compiled by RIVM/MNP.

In the present study the first method has been used as far as possible, as the main focus here is on individual passenger cars. These data are also readily available for all the cars sold in the Netherlands. This also means the presented data are in line with other literature on the subject and with EU and Dutch policies in this area. However, it should be noted that fuel efficiency data obtained under real-life driving conditions should be used if results are to be used to estimate the total CO_2 emission reduction of a specific technology.

5.4 CO_2 emissions of current car/fuel combinations

5.4.1 Conventional petrol and diesel cars

In comparing the CO_2 emissions of different technologies a choice must be made as to which cars to compare. No two cars are the same. For example, a small and large car differ not only in size but also in weight, power, comfort, etc. We will not attempt to single out any one aspect in this section. Instead, per-kilometre CO_2 emissions are given for a selection of cars differing in many aspects. Nonetheless, a number of conclusions can be drawn from these figures.

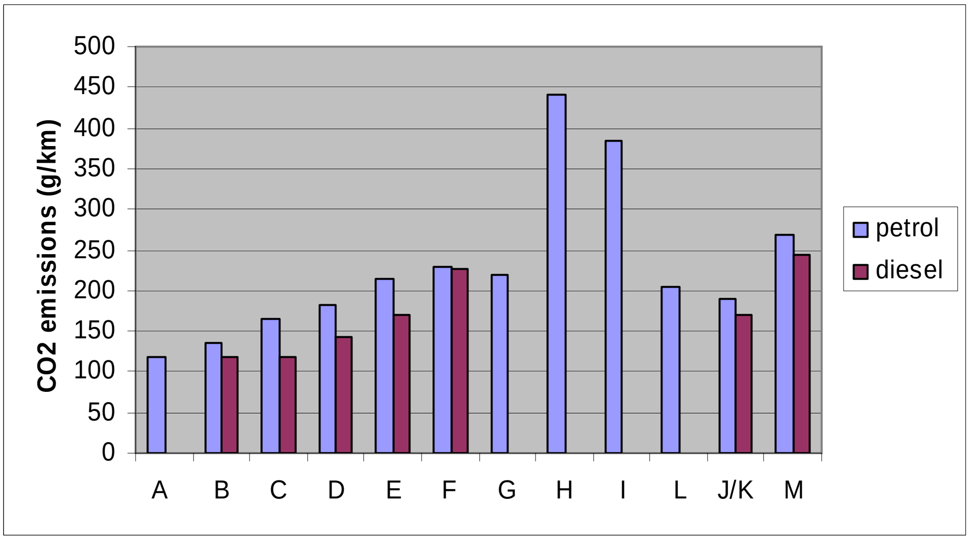
Table 8 shows the CO_2 emission factors of a selection of the petrol and diesel cars currently available (RDW, 2005). Cars are included from various market segments, here not precisely defined in terms of size or comfort, but as a described in Annex B. The data are also depicted graphically, in Figure 19.

Table 8 CO_2 emissions of selected passenger car models

		Petrol		Diesel	
Market seg-ment	Car	Model	Emissions (g CO_2/km)	Model	Emissions (g CO_2/km)
A	Suzuki Alto	1.1	119		
B	Fiat Punto	3-door, 1.2 00AB	136	3-door, 1,3JTD 16m	119
C	Renault Mégane	5-door, 1.4 16v	165	5 door, 1,5 DCI 80	117
D	Citroën C5	1.8 l, 16v 'dc6fzb'	182	1.6hdi 16v 5 'rcghzc'	142
E	Volvo V70	2.4 l, 140 pk	214	2.4d	171
F	Audi A8	162 kW	230	TDI 155 kW	226
G	Alfa Romea GTV	2.0 t.spark 35D	220		
H	Ferrari	360 Modena 3.6 V8	440		
I	Rolls Royce	Phantom	385		
J / K	Opel Zafira	1.6-16v (z1.6xe)	190	2.0dti (y2.odth)	169
L	Subaru Forester	2.0 x awd	204		
M	Ford Transit	v184 e5fab	269	v184 d2fbb	245

Note: Where possible, comparable models have been selected for the petrol and diesel model.
Source: (RDW, 2005).

Figure 19 Comparison of CO_2 emission factors of various currently available petrol and diesel cars



As is clear from these data, the fuel efficiency of conventional petrol and diesel cars varies strongly with the type of car. Smaller cars clearly achieve much lower fuel consumption than larger cars. The fuel consumption of sports cars and very luxurious cars is almost 4 times higher than that of the diesel version of a family car such as the Renault Mégane. Not included in this graph but often in the news is the Hummer, emitting 458 g CO_2/km (Hummer H2, a petrol car).

These data also show that diesel models are generally more fuel-efficient than comparable petrol models.

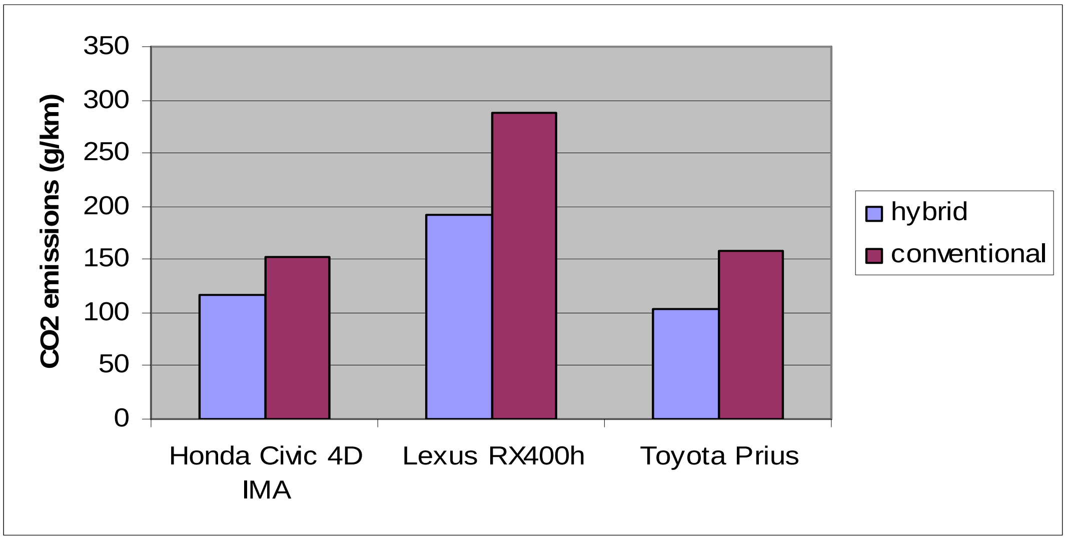
5.4.2 Impact of hybrid technology

Hybrid drive trains can reduce fuel consumption and thus CO_2 emissions considerably. The CO_2 emission factors of currently available hybrid cars are shown in Table 9 and Figure 20. To illustrate the fuel efficiency improvements achieved, the emission factors of comparable cars from the same manufacturer are also included. In this comparison the hybrid technology improves fuel efficiency by between 24% and 35%, with the Honda Civic at the low end and the Toyota and Lexus at the high end of the scale.

Table 9 CO_2 emissions of available hybrids and comparable cars

Hybrid car			Comparable cars	
Type	Model	Emissions (g CO_2/km)	Model	Emissions (g CO_2/km)
Honda Civic 4D IMA	1.3i MT 03	116	1,4i MT 04	153
Lexus RX400h	3.3 Automatic	192	RX300 3.0 Automatic	288
Toyota Prius	1.5HSD	104	Corolla 1.4	159

Figure 20 Comparison of CO_2 emission factors of hybrid and comparable conventional cars

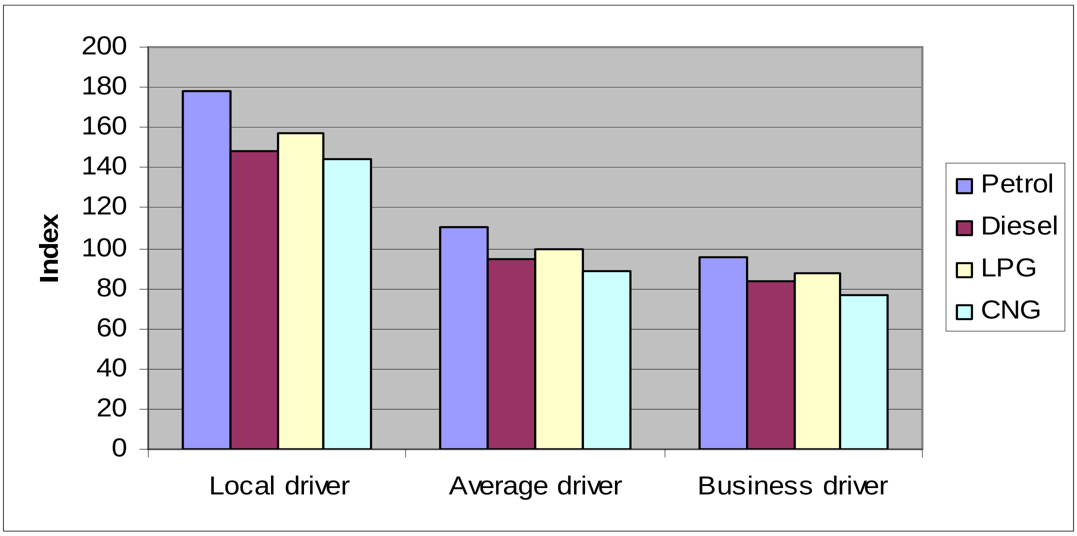


The graph also shows that hybrid technology can reduce CO_2 emissions significantly. However, if used in a heavy SUV such as the Lexus, the emissions remain high in relation to smaller models. A comparison of these data with those for conventional cars (as in Figure 19) shows that both the Toyota Prius and the Honda Civic have specific emissions that are very low indeed. The Lexus has much lower emissions than comparable SUVs, but the cars used as examples of vehicle categories A - D (from ‘small car’ to ‘upper family car’) and the diesel car of category E (‘executive’) in the previous section all have lower emissions than that of the hybrid Lexus.

5.4.3 Comparing conventional fossil fuels

In (TNO, 2003b) the emissions associated with all four fuel types of engine fuel are compared based on measurements. Three different ‘typical’ driving cycles were compared, reflecting different real-life circumstances. The vehicles used were all state of the art 2003 models[36]. The results are shown in Figure 21.

Figure 21 Index numbers of passenger car CO_2 emissions



Note: LGP for average driver = 100.
Source: Based on (TNO, 2003b).

With respect to CO_2 emissions, there is not much difference between diesel and automotive LPG. From earlier research it appeared that diesel cars were more fuel-efficient, but the difference has decreased and it can be expected that in 2010, say, the CO_2 emissions of LPG vehicles will be slightly lower than those from diesel cars. Both have notably better fuel economy than comparable petrol cars. With respect to climate impact, the advantage of LPG over diesel is currently non-existent and will remain small in the future. According to the test results, CNG is slightly better than diesel and LPG. This is in contrast to (OECD, 2004), which concluded that compared to diesel fuel, CNG produces equivalent or higher CO_2 emissions.
Clearly, LPG and/or CNG may have other benefits; for example, they may improve air quality or reduce oil dependence. However, these data show that they are not able to provide significant CO_2 emissions reduction.

[36] Opel-Vectra, Peugeot 406, Renault-Scenic, Volvo-V40 and Ford Focus represented 3 fuels (except CNG), while Opel-Astra and Volvo-V70 ran on all 4 fuels. The Fiat Multipla was there only as a CNG car.

5.4.4 Biofuels

A number of biofuels are already available in various countries worldwide. These fuels are produced from biomass, which takes up the same amount of CO_2 during cultivation as it emits during combustion in the car. These CO_2 emissions do not therefore contribute to the greenhouse effect. However, overall life cycle GHG emissions are not zero, as energy is required for crop cultivation and processing and N_2O emissions arise from fertiliser use (N_2O is a strong greenhouse gas). Typically, these biofuels reduce GHG emissions by 30-60% compared with the petrol or diesel they replace (Ecofys, 2003).

In the EU these biofuels are typically produced from crops such as rapeseed, cereals or sugar beet. Alternatively, residual products from the food and cattle feed industry may be used as a feedstock. If the biomass or biofuels is imported, other types of feedstock may be used, such as sugarcane (used in Brazil for bio-ethanol production), palm oil (as a feedstock for biodiesel) or Jatropha oil, a crop considered to have great potential for biodiesel production.

The production of biofuels requires large amounts of biomass, which, alongside the positive impact may also have negative social and environmental effects if not managed properly. Clearly, large-scale use of these fuels will have a significant impact on the biomass market. Other potential users of the biomass, such as the food or cattle fodder industry, or the electricity sector, may be faced with higher prices for biomass or other agricultural products. The agricultural sector is likely to benefit from these developments, although it is not yet clear where the biomass will be cultivated (i.e. what country or region will benefit). Furthermore, since large-scale biofuel production will increase biomass cultivation worldwide, there may be a number of risks in terms of sustainability. There may be increased pressure on high-conservation areas and cropland for food production owing to greater demand for farmland. There may also be effects, especially in developing countries, that are socially undesirable. Indeed, in the case of palm oil cultivation some of these impacts recently became apparent. Clearly, such potentially negative consequences should be avoided, by introducing a biomass certification and control system, for example.

Biodiesel and bio-ethanol are the biofuels with the largest market share in Europe, although they are not (yet) on sale in the Netherlands. In this country small-scale production of pure plant oil (PPO) was introduced in 2005.

Since biofuels are more expensive than diesel and petrol, they will only be able to penetrate the market if government incentives like reduced excise duty are put in place. This has indeed been done in various EU Member States over the past few years and will be implemented in the Netherlands from 1-1-2006 onwards. However, the plan is to replace this policy measure with an obligation for oil companies to sell a minimum amount of biofuels each year (2% in 2007).

Besides these fuels, there are a number of biofuel production processes under development that are expected to perform better environmentally (e.g. lower net CO_2 emissions, less fertiliser use), at lower cost (CE, 2005). The main benefits are expected to accrue from the different biomass sources. These processes can convert lignocellulosic (i.e. woody) biomass, which requires less land for cultivation than rapeseed, sugar beet or cereals and does not compete with the food chain. These so-called second generation biofuels are expected to come onto the market on a significant scale in about 8-10 years' time, but research efforts will depend strongly on government incentives and policies (CE, 2005). These will be discussed later, in Section 5.5.2.

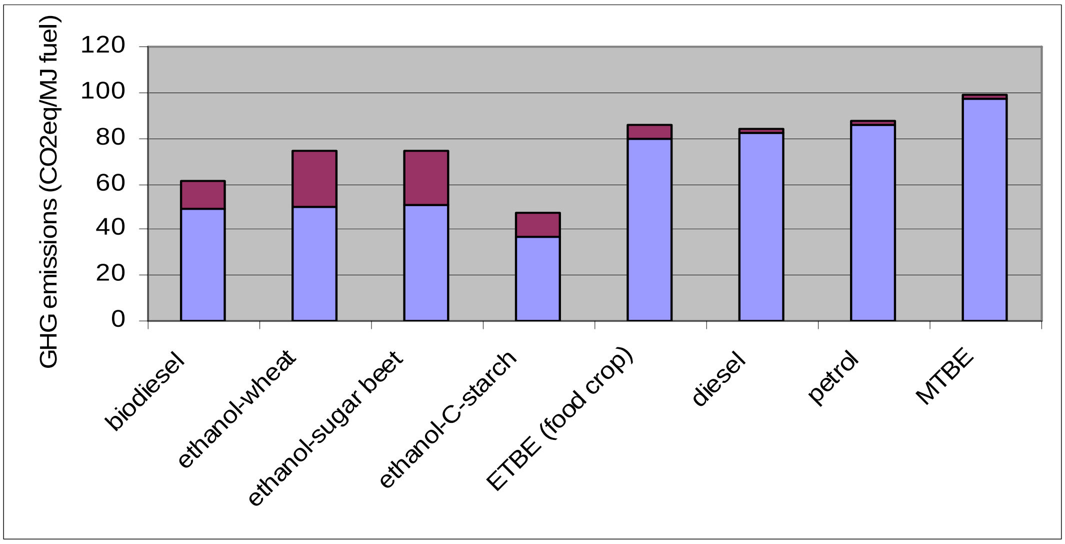
The various biofuels currently available are listed in Table 10, together with their main characteristics. Their GHG reduction potential and production costs, compared to the fossil fuels they replace, are shown in Figure 22 and Figure 23. Pure plant oil is not included in these graphs because it is likely to remain a niche fuel, whereas the other fuels can be expected to come on the market on a much larger scale. PPO can only be used in suitably adapted cars and has varying properties and characteristics (depending on the type of plant oil used).

The first figure shows that these biofuels indeed reduce GHG emissions compared with the fossil fuels they replace. The reduction depends on the biofuel in question but also on the biomass feedstock, as a significant portion of GHG emissions depends on the emissions occurring during biomass cultivation. The average GHG emissions reduction of biodiesel and bio-ethanol is about 30-60%. ETBE achieves only about 15% GHG reduction, because it is only partly of biological origin (bio-ethanol, the other component being fossil isobutylene). In some cases the ranges in the data are quite large, because GHG emissions depend on many factors. The emission data for biomass cultivation, especially, can only be estimated within a broad band of uncertainty.

Table 10 Current biofuels and their main characteristics

	Commonly used biomass feedstock	To be used in diesel or petrol engines?	
Pure Plant Oil	Rapeseed	Diesel	Cannot be blended in diesel, but can be used in adapted diesel cars.
Biodiesel	rRapeseed	Diesel	Can be blended in diesel, with no engine modifications required for blends up to about 15%.
Bio-ethanol	Grain or sugar residues	Petrol	Can be blended in petrol, with no engine modifications required for blends up to about 20%.
ETBE	Grain or sugar residues	Petrol	Is made from ethanol, can replace MTBE, a petrol additive. Max. percentage allowed in petrol: 15%.

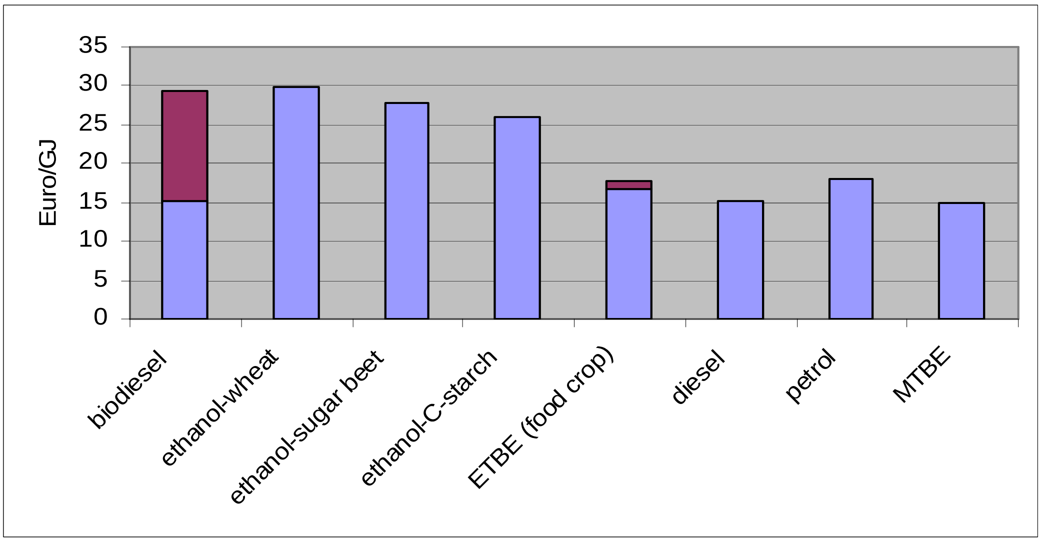
Figure 22 Greenhouse gas emission reduction of various currently available biofuels compared with the GHG emissions of petrol and diesel



Source: (CE, 2005). NB. The red bars indicate ranges in data.

As Figure 23 shows, the production costs of these biofuels are (significantly) higher than those of current fuels, although the ranges are significant. Note that biofuel costs are shown here in Euro/GJ and not in Euro/litre, as the energy content of the biofuels is not always the same as that of their fossil counterparts (especially in the case of ethanol). Comparing costs per litre can therefore give misleading results. To put these data into perspective: 1 GJ diesel equals 31.75 litres, 1 GJ petrol equals 28.10 litres.

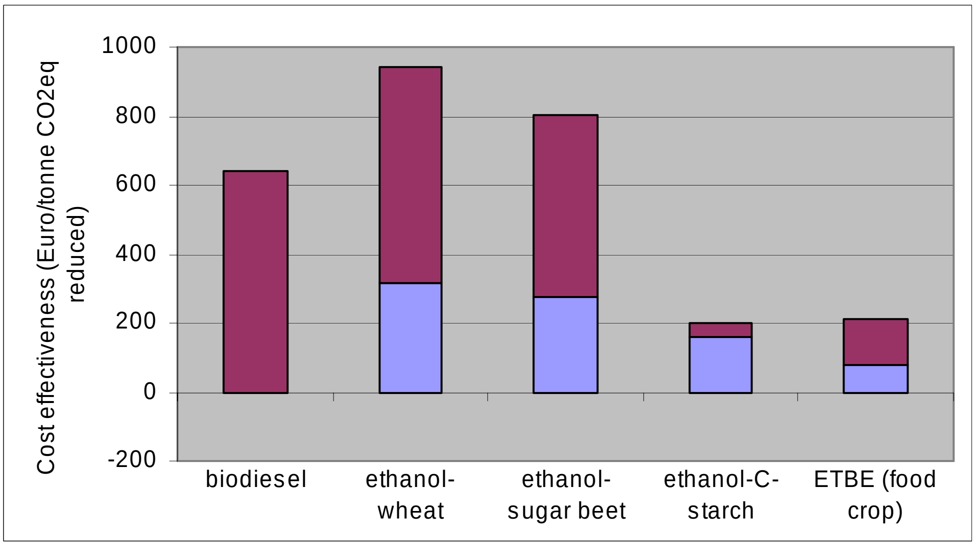
Figure 23 Production cost of various currently available biofuels compared with current cost of petrol and diesel (end of September, 2005)



Source: (CE, 2005). NB. The red bars indicate ranges in data.

Figure 24 shows the cost effectiveness of GHG reduction with these biofuels. Cost effectiveness is defined here as the ratio between the additional costs of these fuels relative to the GHG reduction they achieve, with the result expressed in Euro per tonne CO_2-eq. reduced[37]. There are clearly large differences between the biofuels shown here, and the ranges are large (due to the ranges in cost and GHG reduction seen in the two previous figures). It can also be concluded that the cost of GHG reduction with these biofuels is relatively high, with the exception of the lowest cost estimate for biodiesel (where biodiesel costs equal current diesel costs) and ETBE, again if the low cost estimate can be attained. For comparison, the current cost of CO_2 emission rights in the EU Emission Trading System (ETS) is about 20-30 Euro/tonne CO_2-eq.

Figure 24 Costs effectiveness of GHG reduction with various currently available biofuels (using petrol and diesel costs of end of September, 2005)



Source: (CE, 2005). NB. The red bars indicate ranges in data.

On average, then, promotion of these biofuels is obviously a relatively expensive form of climate policy. However, this does not automatically mean they should not play a role in efforts to mitigate CO_2 emissions from cars. As explained earlier, fuels that emit less CO_2 than current, fossil fuels will be necessary to achieve significant CO_2 emission reductions in this sector. As we shall show in the next section, moreover, better performing biofuels are likely to come onto the market in the coming 10-15 years if research efforts are continued. We therefore see a number of reasons why implementing biofuels policies in the short term might be advantageous in the longer term:

- Current biofuels can be used to gain experience with these new fuels (consumers, manufacturers, governments, etc.).
- Current biofuel policies can be implemented in such a way as to accelerate the development and market introduction of better performing biofuels.

[37] The fossil fuels are not included in this graph because 'cost effectiveness' is meaningful only for CO_2 reducing measures, i.e. for the biofuels.

- Sustainability standards (for example for biomass cultivation) can be developed.

In implementing policies, then, attention should be given to the sustainability of these biofuels right from the start.

5.4.5 Flex-fuel cars

Current passenger cars can only use biodiesel, bio-ethanol and ETBE in blends of up to 15% or 20% with diesel or petrol. If higher percentages are to be applied, engines need to be modified.

For bio-ethanol, special cars have come onto the market: so-called flex-fuel vehicles. Because ethanol is more corrosive than petrol, they have a somewhat adapted engine and fuel system. They also have a special sensor in the fuel line to analyse the fuel mixture and control fuel injection and timing to adjust for different fuel compositions. They can run on any blend of petrol and ethanol.

5.4.6 Hydrogen

Hydrogen is an energy carrier that might provide environmental benefits in the long term, but it will still be some time before commercial use is indeed attractive. Hydrogen will therefore be discussed in the next section, on future technologies.

5.5 Potential of future technologies

5.5.1 Vehicle technologies

Several studies have been carried out in recent years to estimate the potential fuel efficiency improvements of current passenger cars (Ricardo, 2003) (SRU, 2003) (IEEP, 2005) (TNO, 2003a). The most relevant results are given in Annex A.

The studies show that a substantial reduction of CO_2 emissions is feasible with technologies that are currently on the market or can be introduced in the near future. This holds for all types of car, from small to large and from petrol to diesel. The following technological improvements show greatest potential:

- Hybrid technology.
- Start-stop alternator.
- Variable valve timing.
- Engine downsizing[38].

Consumer choice need not be limited to achieve substantial emission reductions. By applying a mix of technologies a CO_2 emissions reduction of 25-50% per kilometre is feasible and need not be costly. Several studies actually stresss the fact that the cost of many of these technological improvements may well be below the financial benefits of the ensuing fuel savings.

[38] Note that this is feasible without reducing consumer choice because of improved driving performance.

(IEEP, 2005) concludes that average CO_2 emissions of 140 g/km can be achieved in new passenger cars in a cost effective way, i.e. the fuel benefits are outweigh the additional vehicle costs. The EU target of 120 g/km for 2010 can be achieved at relatively low cost.

5.5.2 Biofuels

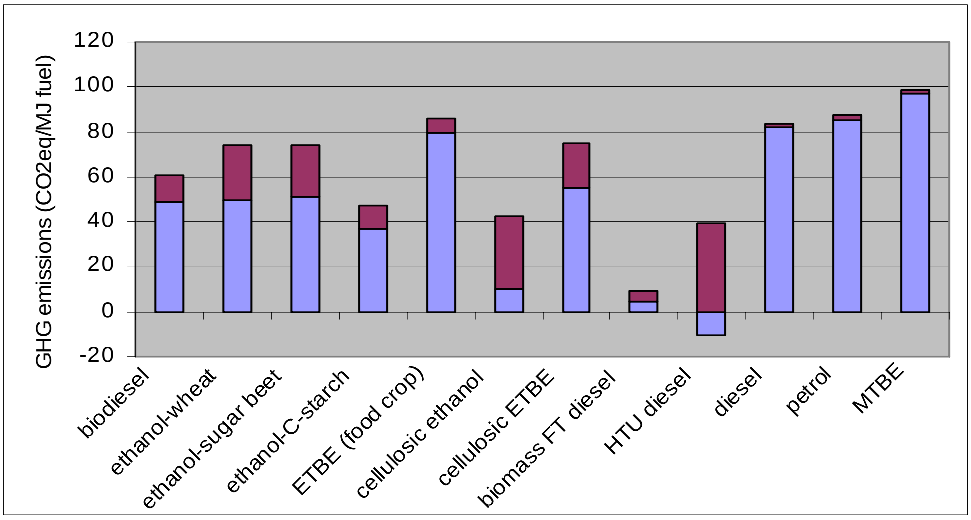
As mentioned in Section 5.4.4, biofuels are currently being developed that are expected to perform better than their current counterparts from both an environmental and an economic point of view. These are briefly reviewed in Table 11.

Table 11 Future biofuels and their main characteristics

	Commonly used biomass feedstock	To be used in diesel or petrol engines?	
Biomass Fischer Tropsch diesel	Woody residues, cultivated wood	Diesel	Can be blended in diesel up to 100%. Free of sulphur and aromatics.
Bio-ethanol from lignocellulosic biomass	Woody residues, cultivated wood	Petrol	Same characteristics as current ethanol.
ETBE from lignocellulosic biomass	Woody residues, cultivated wood	Petrol	Same characteristics as current ETBE.
HTU diesel	Wet organic biomass	Diesel	Expectations are that it can be blended with diesel without engine modifications.

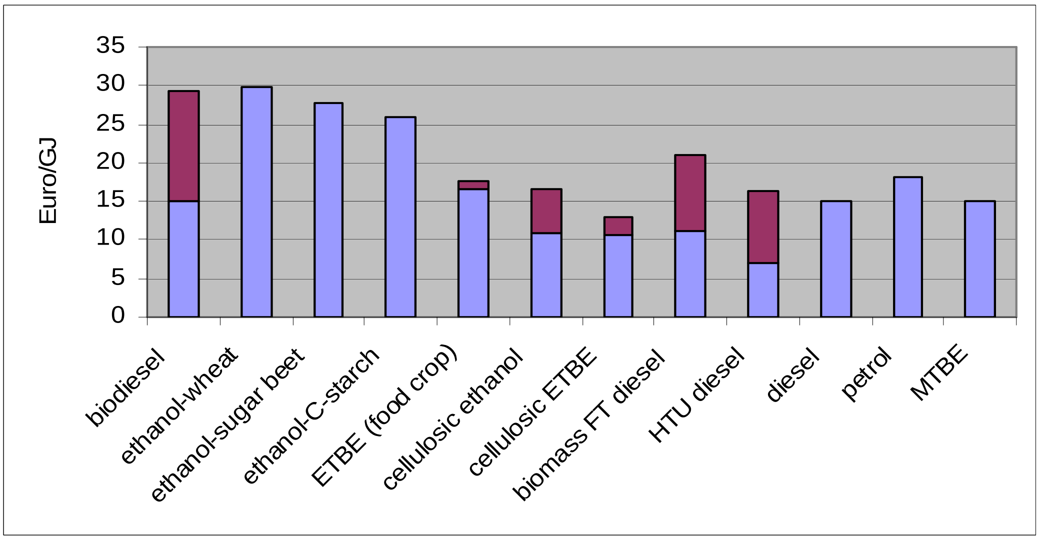
Current estimates of the GHG emissions, production costs and cost effectiveness of these biofuels are shown in Figure 25, Figure 26 and Figure 27. GHG emission reductions of 50-115% are currently expected (once more with the exception of ETBE), again strongly dependent on the biomass used as feedstock. If woody residues are used for ethanol or biomass FT production, GHG emission reductions are expected to be about 80-90%. Costs are expected to be significantly lower than those of current biofuels and may even be lower than the current costs of petrol and diesel. These figures result in a cost effectiveness that is much lower than current biofuels and perhaps even negative, as can be seen in Figure 27 (negative cost effectiveness means both GHG emissions and costs are lower than those of the fossil fuels they replace).

Figure 25 Greenhouse gas emissions of future biofuels compared with those of currently available biofuels, petrol and diesel



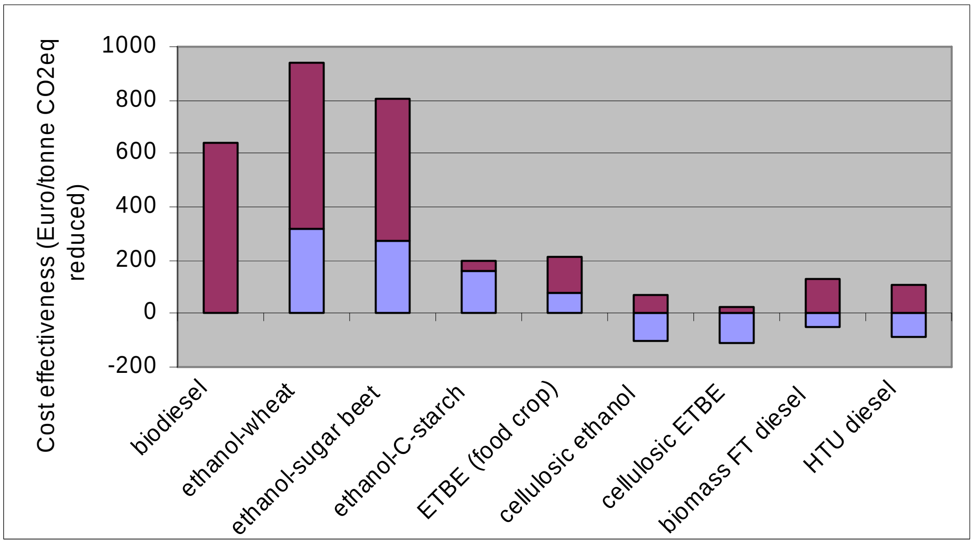
Source: (CE, 2005). NB. The red bars indicate ranges in data.

Figure 26 Production costs of future biofuels compared with those of currently available biofuels and fossil fuels (end of September, 2005)



Source: (CE, 2005). NB. The red bars indicate ranges in data.

Figure 27 Cost effectiveness of GHG reduction with future biofuels compared with that of currently available biofuels (using petrol and diesel costs as of end of September, 2005)



Source: (CE, 2005). NB. The red bars indicate ranges in data.

Besides GHG and cost benefits, other environmental benefits can be expected from these future biofuels. They can be produced from woody biomass (for example, residues from forestry or agriculture or miscanthus or poplar cultivation), which has a higher yield (expressed in litres biofuel per hectare) than rapeseed, sugar beet or cereal cultivation. Less land is therefore required to produce the same amount of biofuel, or, conversely, more biofuel can be produced from the land available for energy crops. This reduces overall pressure on nature and wildlife areas. Furthermore, there is less competition with the food or cattle feed sector[39], since woody biomass is much less useful in these sectors than the products used for current biofuels.

5.5.3 Hydrogen

If used in combination with a fuel cell, hydrogen has the potential to reduce car emissions to practically zero. Before this can become reality, though, there are still several, mainly technical obstacles to be overcome. At present the most important of these are problems with hydrogen storage (storing sufficient hydrogen in a reasonably small tank to achieve an acceptable driving range is still technically difficult) and high cost (mainly of storage systems and fuel cells).

With regard to CO_2 reduction, hydrogen has the potential to reduce emissions significantly if it is produced from renewable energy and used in combination with fuel cells (which achieve a higher efficiency than combustion engines). Total emissions of no more than 10 g CO_2-eq/km could then be achieved (SRU, 2005). However, current practice in the chemical industry, for example, is that hydrogen is produced from fossil fuels. Given the additional processing steps involved, using fossil fuel based hydrogen in cars may increase CO_2 emissions

[39] Competition with the electricity sector remains, though.

significantly, compared with direct use of these fossil fuels in the same vehicles (SRU, 2005). As hydrogen can be produced using a range of energy sources, though, it has the additional potential advantage of being very flexible in this respect.

However, the efficiencies that can be achieved in mobile emission sources such as cars are significantly lower than those attainable with stationary sources such as power plant. Therefore, and in view of the problems still encountered with hydrogen storage, it makes more sense from both an economic and environmental perspective to use renewable hydrogen in the electricity sector, at least as long as renewable energy sources are scarce. Considerable research efforts have nonetheless been put into long-term technological development of hydrogen-fuelled cars - mainly because of the drive to develop zero-emission vehicles.

5.6 Conclusions

There are a number of technologies available to reduce car CO_2 emissions. Hybrid drive systems are clearly one such technology. However, today's conventional cars also differ widely in their fuel efficiency, with smaller cars achieving much better fuel economies than larger vehicles like SUVs, MPVs and luxury models, for example. In addition, diesel cars are more fuel-efficient that petrol cars. A shift to diesel may have a negative impact on emissions of pollutants like NO_x and PM_{10}, however, although this can be solved using advanced engine and filter technologies.

Note that while the use of hybrid technology in a large and heavy car like a SUV will reduce the vehicle's CO_2 emissions significantly, its emissions may still be higher than those of conventional but smaller and lighter cars.

Recent studies show that technology is available to substantially reduce the fuel consumption and thus the CO_2 emissions of new passenger cars. Down to about 130 g/km these changes are even expected to be profitable, with fuel savings benefits outweighing additional vehicle costs. Hybrid drive systems have major potential for improving fuel efficiency, but other technological improvements to current, conventional engines can also contribute to CO_2 emission reductions.

Biofuels are presently the only alternative fuel that can reduce CO_2 emissions significantly. Today's biofuels reduce GHG emissions by about 30-60%, but the production costs are generally still high. Biofuels with improved environmental and economical performance are currently being developed and are expected to come onto the market within the next 10 years.

Those biofuels that are not produced from biomass residues require large-scale biomass cultivation, which may have a negative environmental impact as it increases pressures on high-conservation areas and cropland for agricultural production.

Government policies are very important drivers for development of the more sustainable biofuels, as biofuel producers and oil companies will only invest in research and development if they expect sufficiently large sales of these products (and thus returns on their investments). Government incentives will therefore be needed to steer the market in a sustainable direction.

Hydrogen might be an environmentally attractive option in the long term, if it is produced from renewable energy sources. Before this option becomes attractive, though, costs will need to be reduced significantly and a number of technological hurdles taken.

6 Literature

6.1 References

ADAC, 2005
Study on the effectiveness of Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO_2 emissions in respect of the marketing of new passenger cars
Final report, March 2005

Annema, 2001
J.A. Annema, E. Bakker, R. Haaijer, et al.
Stimuleren van verkoop van zuinige auto's : de effecten van drie prijsmaatregelen op de CO_2-uitstoot van personenauto's (summary in English)
2001

Belastingdienst, 2005a
Belasting van personenauto's en motorrijwielen (BPM)
Downloaded from http://www.belastingdienst.nl/9229237/t/bpm.htm, 4-11-2005

Belastingdienst, 2005b
Personenauto's, motorrijtuigenbelasting
Downloaded from http://www.belastingdienst.nl/mrb/download/650.html, 4-11-2005

BOVAG-RAI, 2005
Mobiliteit in cijfers 2005; Auto's

CE, 2001
Hebben autobelastingen en accijnzen effect? : invloed van auto- en brandstof-belastingen op het autopark en –gebruik in 8 EU-lidstaten (Are car and fuel taxes effective? Impact of car and fuel taxes on the car fleet and car usage in 8 EU Member States)
Delft : CE, 2001 (in Dutch)

CE, 2004
The price of transport : overview of the social costs of transport
Delft : CE, 2004

CE, 2005
Biofuels under development : an analysis of currently available and future bio-fuels, and a comparison with biomass application in other sectors
Delft : CE, 2005

CEMT/CM(2003)10
European Conference of Ministers of Transport, Council of Ministers
Monitoring of CO_2 emissions from new cars
27 March 2003

COM(2005) 261 final
Proposal for a Council Directive on passenger car related taxes
5 July 2005

COM(2005) 269 final
Communication from the commission to the council and the European Parliament
Implementing the Community Strategy to reduce CO_2 emissions from cars : fifth annual Communication on the effectiveness of the strategy

COWI, 2002
Fiscal measures to reduce CO_2 emissions from new passenger cars : main Report
COWI, 2002

DHV, 2004
Business case LPG, Positionering van LPG in maatschappelijke discussie rond ketenstudie (in Dutch)
DHV Milieu en Infrastructuur, 2004

Directive 1999/94/EC
Directive 1999/94/EC of the European Parliament and of the Council of 13 December 1999 relating to the availability of consumer information on fuel economy and CO_2 emissions in respect of the marketing of new passenger cars

Directive 2003/30/EC
Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport

EEA, 2005
TERM Annual report, to be published

EC, 2004
European Commission
EU emission trading; An open scheme promoting global innovation to combat climate change
Belgium, 2004
Available via
http://europa.eu.int/comm/environment/climat/pdf/emission_trading2_en.pdf

EC, 2005
Member state reports on the implementation of Directive 2003/30/EC, available via: http://europa.eu.int/comm/energy/res/legislation/biofuels_members_states_en.htm)

ECN/RIVM, 2005
Referentieramingen energie en emissies 2005 – 2020 (Energy and emissions reference projection 2005 – 2020)
Petten, 2005

Ecofys, 2003
Biofuels in the Dutch market: a fact-finding study, Ecofys, published by Novem, report 2GAVE03.12
Ecofys, 2003

Eurostat, 2005
Harmonized indices of consumer prices – Annual Data : new Cronos database: THEME2 Economy and Finance, table: haind
Downloaded from Eurostat's data explorer, September 2005
http://epp.eurostat.cec.eu.int

Financiën, 2005
Ministerie van Financiën (Dutch Ministry of Finance)
Memorie van Toelichting Belastingplan 2006 (in Dutch)
http://www.minfin.nl/default.asp?CMS_ITEM=MFCWD5CC76BAE136A4D4285F2A1B4877FDE80X2X35943X39#_Toc114641659 20-10-2005

Goodwin, 2003
P. Goodwin, J. Dargay, M. Hanly
Elasticities of road traffic and fuel consumption with respect to price and income : a review, ESRC Transport Studies Unit, University College London (www.transport.ucl.ac.uk), commissioned by the UK Department of the Environment, Transport and the Regions (now UK Department for Transport)
2003

Greene, 2005
D.L. Greene
Improving the nation's energy security: can cars and trucks be made more fuel efficient? : testimony to the U.S. House of Representatives Science Committee
2005

Inland Revenue, 2004
Report on the evaluation of the company car tax reform
Inland Revenue : 29 April 2004

Kågeson, 2005
Per Kågeson (Nature Associates), T&E 05/1, 2005
Reducing CO_2 emissions from new cars : a progress report on the car industry's voluntary agreement and an assessment of the need for policy instruments

NRC, 2002
National Resource Council, Committee on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards
NRC, 2002

OECD, 2004
Organisation for Economic Co-operation and Development
Can cars come clean? Strategies for low-emission vehicles
Paris, 2004

OECD/IEA, 2005
Making cars more fuel efficient; Technology for real improvements on the road
ECMT European Conference of Ministers of Transport, IEA International Energy Agency
France, 2005

Oil bulletin, 2005
Oil bulletin of the European Commission
http://europa.eu.int/comm/energy/oil/index_en.htm, consulted 4-11-2005

RDW, 2005
Brandstofverbruiksboekje (Fuel Consumption Guide, in Dutch)
January 2005

Ricardo, 2003
Ricardo Consulting Engineers
'Carbon to hydrogen' roadmaps for passenger cars: Update of the study for the department for transport and the department of trade and industry
Ricardo Consulting Engineers, 2003

RIVM/Muconsult, 2001
Stimuleren van verkoop van zuinige auto's; De effecten van drie prijsmaatregelen op de CO_2-uitstoot van personenauto's (in Dutch)
RIVM/Muconsult, 2001

RIVM, 2003a
Briefnotitie Referentieraming
RIVM, 2003

RIVM, 2003b
Scenario's voor duurzame energie in verkeer en vervoer, Beoordeling op verschillende criteria voor duurzaamheid (in Dutch)
RIVM : report 773002025/2003, 2003

SRU, 2005
German Advisory Council on the Environment
Reducing CO_2 emissions from cars; Section of 'Special Report on Environment and Road Transport'
SRU, 2005

TNO, 2002
TNO Inro rapport 2002-64
De zakenautorijder aan het begin van de 21e eeuw (in Dutch)
Delft : TNO, 2002

TNO, 2003a
Future emissions of passenger cars; Expert judgement on the long term possibilities of conventional emission abatement technology
TNO report 03.OR.VM.018.1/RSM, TNO Automotive
Delft : Delft, 2003

TNO, 2003b
Evaluation of the environmental impact of modern passenger cars on petrol, diesel, automotive LPG and CNG
TNO report 03.OR.VM.055.1/PHE, TNO Automotive
Delft : TNO, 2003

VTPI, 2005,
Victoria Transport Policy Institute, TDM Encyclopedia, Transportation elasticities, http://www.vtpi.org/tdm/tdm11.htm consulted on 4-11-2005

6.2 Websites

Statline
Website of Statistics Netherlands, www.statline.nl

7 List of abbreviations

CNG	compressed natural gas
LPG	liquefied petroleum gas
MRB	Dutch annual circulation tax (*Motorrijtuigenbelasting*)
BPM	Dutch vehicle registration tax (*Belasting van Personenauto's en Motorrijwielen*)
HTU	hydrothermal upgrading
SUV	sports utility vehicle
MPV	multi-purpose vehicle
GHG	greenhouse gas
WNF	*Wereld Natuur Fonds*, the Dutch branch of the Worldwide Fund for Nature, WWF

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Cool cars, fancy fuels

A review of technical measures and policy options to reduce CO_2 emissions from passenger cars

Annexes

Report

Delft, November 2005

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A Vehicle and fuel technologies

A.1 Introduction

This annex presents a brief discussion of the various engine technologies cited in the main report. The main focus will be on the fuel efficiency of the engines concerned and their potential for further improvement on this count.

A.2 Conventional fuel vehicles

In this section we have compiled the results of several recent studies on technical solutions for fuel efficiency improvements to passenger cars.

Ricardo (2003) has studied the potential for reducing the CO_2 emissions of a mid-size (segment C/D) diesel car. An overview of the impact of improved fuel efficiency is given in Table 12.

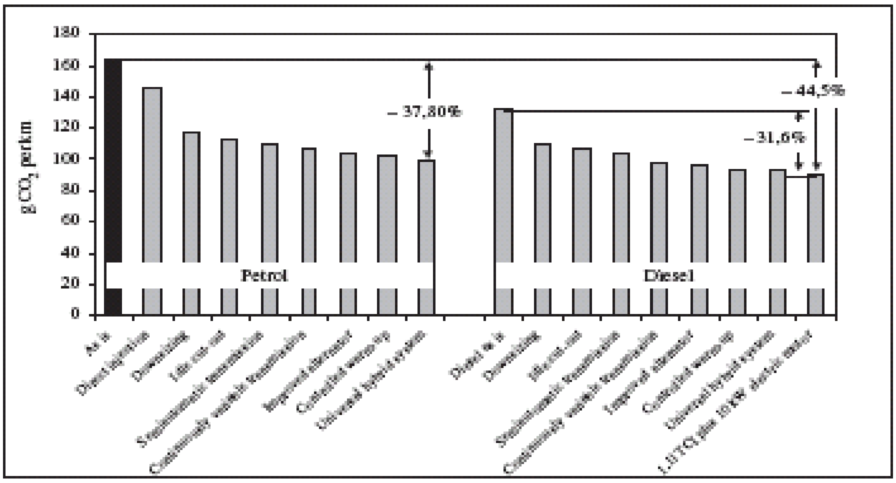
Table 12 CO_2 emission abatement technologies and their costs

Step Year	Technology	CO_2 (g/km)	Improvement	Cost, relative to step 0
0	2003 reference car (1.9 litre engine, 82kW, 1351 kg)	152	-	-
1 2004	12 volt alternator (stop-start), 6 gear manual gearbox, 1.8 litre engine, Euro 4	145	4.6%	1.5%
2 2007	42 volt belt hybrid, automated ‘dualclutch’ gearbox, 1.6 litre engine, Euro 4	117	23.0%	5.8%
3 2010	42 v mild hybrid, NiMH battery, regenerative breaking, 1.2 litre engine (63kW/l), Euro 5	100	34.2%	13.3%
4 2012	Parallel hybrid, advanced engine (1.0 litre) Li-ion batteries, light-weight materials, Euro 5	83	45.4%	23.5%
5 2017	Parallel hybrid, exhaust heat recovery, higher voltage, improved supervisor control system, light-weight materials, Euro 5	77	49.3%	24.3%

Source: Table taken from Kågeson (2005), based on Ricardo (2003).

A different overview with similar implications is provided in SRU (2005); see Figure 28.

Figure 28 Effects of various technical measures on fuel efficiency of petrol (left) and diesel (right) cars, according to SRU (2003)



NB. This graph is not legible, please refer to the original drawing in SRU (2003).

The most complete and recent overview of technological improvements and their impact on fuel economy is provided by IEEP/TNO/CAIR (2005).

Table 13 Impact of technological improvements on fuel economy of petrol cars (percentage fuel efficiency improvement)

	Car size	Small	Medium	Large
	Description			
Engine	Optimised engine efficiency	4	4	4
	Direct injection / stratified charge (lean burn operation)	10	10	10
	Direct injection / homogenous charge (stoichiometric)	5	5	5
	Mild downsizing with turbo charging	10	10	10
	Medium downsizing with turbo charging	15	15	15
	Strong downsizing with turbo charging	20	20	20
	Variable valve timing	6	6	8
	Variable valve control	8	8	11
	Cylinder deactivation	10	10	14
Transmission	6-speed manual/automatic gearbox	3	3	3
	Piloted gearbox	5	5	5
	Continuous variable transmission	9	9	9
	Dual-Clutch	4	4	4
Hybrid	Start-stop function	6	4	3
	Regenerative braking	5	7	8
	Mild hybrid (motor assist)	8	11	13
	Full hybrid (electric drive)	17	20	23
Body	Improved aerodynamic efficiency	2	1.5	1
	Mild weight reduction	3	3	5
	Medium weight reduction	5	6	11
	Strong weight reduction	8	9	16
Other	Low friction tyres	2	2	2
	DeNOx catalyst	-1	-1	-1

Source: Table 3.4 from IEEP/TNO/CAIR (2005).

Table 14 Impact of technological improvements on fuel economy of diesel cars (percentage fuel efficiency improvement)

	Size of car	Small	Medium	Large
	Description			
Engine	Optimised engine efficiency	4	4	4
	16 valve cylinder head	4	4	4
	Piezo injectors	0	0	0
	Mild downsizing with turbo charging	10	10	10
	Medium downsizing with turbo charging	15	15	15
	Strong downsizing with turbo charging	20	20	20
	Cylinder deactivation	10	10	12
Transmission	6-speed manual/automatic gearbox	3	3	3
	Piloted gearbox	5	5	5
	Continuous variable transmission	9	9	9
	Dual-clutch	4	4	4
Hybrid	Start-stop function	5	4	3
	Regenerative braking	5	7	9
	Mild hybrid (motor assist)	8	11	14
	Full hybrid (electric drive)	15	20	25
Body	Improved aerodynamic efficiency	2	1.5	1
	Mild weight reduction	3	3	5
	Medium weight reduction	5	6	11
	Strong weight reduction	8	9	16
Other	Low friction tyres	2	2	2
	DeNOx catalyst	-1	-1	-1
	Particulate trap	-2	-2	-2

Source: Table 3.5 from IEEP/TNO/CAIR (2005).

It should be noted that the emission reduction percentages cited in this study cannot always be added, as some of the technological options are mutually exclusive. In addition, the impact of implementing several options simultaneously is multiplicative rather than additive.

TNO (2003a) describes the potential of several options for improving current technologies. Here we briefly report the main results.

There are various ways to improve the fuel efficiency of stoichiometric spark ignition engines, most of them involving improvement of the part-load efficiency. According to TNO (2003a) there are various options:

- Variable valve timing.
- Variable compression.
- Direct fuel injection.
- Engine downsizing.
- Cylinder shut-off.
- Application of a so-called starter-alternator system.
- Hybrid propulsion system.

With a combination of these measures fuel efficiency improvements of up to 25% will be possible over the next 10 years TNO (2003a).

The fuel consumption of direct injection (DI) diesel cars is about 25% lower than that of cars with spark-ignited (petrol) engines. Owing to the difference in energy density of the respective fuels, there is only about 14% difference in the CO_2 emissions of diesel and petrol cars. According to TNO (2003a) there is only limited potential for further improving the efficiency of diesel engines. Hybrid technology could lead to a 10-15% reduction in fuel efficiency; see below.

Non-stoichiometric spark ignition engine

One option for reducing fuel consumption is the non-stoichiometric spark ignition engine. According to TNO (2003a) this may reduce fuel consumption by 10- 20%. This technology would result in significantly higher NO_x emissions, however. For further discussion, see (TNO, 2003a).

Hybrid technology

According to TNO (2003a), hybrid drives in combination with a host of other vehicle-side adaptations can achieve a significant reduction in fuel consumption. Based on computer simulations, spark ignition petrol vehicles will consume 30-45% less fuel if fitted with a parallel hybrid drive. For vehicles with a diesel engine, a fuel consumption benefit of 15% may be feasible.

In the past few years, hybrid technology has entered the passenger car market. The Toyota Prius is currently market leader, but the example has been followed by other manufacturers. The hybrid drive combines a conventional combustion engine with an electrical drive train, resulting in significant fuel efficiency improvements.

OECD/IEA (2005) discusses hybrid technologies as a way of making cars more fuel-efficient. Hybrid power trains can improve efficiency by the following means:

- Engine shut-off during idle/braking.
- Launch assist.
- Regenerative braking.
- Electric traction at low speeds.
- Transmission optimisation.

This list is arranged in order of increasing electrical energy storage requirements and increasing cost. Two examples of hybrid systems are discussed in more detail in (OECD/IEA, 2005). We repeat them here because they are of relevance to current and future developments with respect to the hybrids on the market. We will return to this issue at the end of the discussion.

A ‘mild’ 42V hybrid system improves fuel efficiency primarily by shutting the engine down during braking and idle. Vehicles in city traffic do not actually use their engine power for about 45 per cent of the time. This can improve fuel economy by 7 to 9% on the city cycle, but has no benefits for motorway driving. It should be noted that the shut-down feature is not initiated until the engine is fully warmed up, so that fuel economy is not improved at cold temperatures or on short trips.

The 42V system can also provide fuel economy benefits from increased electrical system efficiency (1%) and from modest levels of braking energy recovery and launch assist (1 to 2%).

High voltage (300+V) ‘full’ hybrid systems are capable of providing far more electrical power. On top of the improvements associated with the 42V system, it allows for significant engine downsizing, electrical traction at low speeds and much more braking energy recovery. However, the system is not efficient at higher power demands.

Clearly, the costs associated with a ‘full’ hybrid system are much higher than with a mild system. The hybrid cars currently on the market have a high-voltage system that increases the vehicle price substantially but also provides significant fuel economy improvements.

A.3 Alternative fuel vehicles

In this section we discuss some of the general aspects of alternative fuels and their environmental performance and elaborate on the future potential of selected technologies. The discussion is complemented with specific data from test results. The discussion is based heavily on OECD (2004), TNO (2003a, 2003b), and SRU (2005).

Compressed natural gas
Natural gas can be used for transport, either in the form of highly compressed natural gas (CNG) or as liquefied natural gas (LNG). It has a lower energy density than petrol and its range is therefore relatively low. To obtain the same amount of energy some 4 (diesel) to 4.5 (petrol) times greater volume must be carried if the gas is compressed. The advantage of carrying natural gas as LNG is its low volume. However, it must then be stored in a well-insulated tank at temperatures below -162 degrees Celsius.

In assessing the potential benefits with respect to CO_2 emissions, account should be taken of ‘well-to-tank’ emissions. These depend very much on assumptions regarding origin, transportation routes and pipeline losses. Assuming the current most favourable EU route, the well-to-tank emissions could be 30% below those of petrol. Using different assumptions, however, other studies calculate GHG emissions as 60-85 % higher than those of petrol.

Bivalent vehicles can run on either petrol or natural gas and thus go some way in overcoming the problem of limited natural gas infrastructure. In some instances, however, burning natural gas in a petrol engine in bivalent vehicles is still less efficient than petrol combustion. In adapted engines CO_2 emissions may be about 20 % lower, resulting in similar levels to those achieved by diesel engines. The projected emissions of these vehicles in 2010 are similar to the figures for conventional fuels in improved combustion engines. This is without taking the upstream supply chain into account.

Synthetic diesel from natural gas

Natural gas can also be used as a feedstock to produce synthetic diesel. This would have the advantage of obviating the need for new filling station infrastructure or vehicle conversion. Compared with conventional diesel, synthetic diesel offers improved quality with better ignition and emissions free of sulphur, nitrogen and aromatics. The additional conversion requires energy, however, resulting in an overall negative impact on CO_2 emissions. The use of processed natural gas as synthetic diesel would not lead to a decline in greenhouse gas emissions.

Electric vehicles

Electric vehicles are often regarded as a desirable technology in urban areas, producing zero local emissions during operation. From a CO_2 perspective, however, this is less important. The CO_2 emissions of electric cars depend strongly on the type of electricity used to charge the batteries.

Electric vehicles have a high level of comfort and good acceleration. They also have a number of serious disadvantages, though, including high cost, short range, long recharge times and a lack of battery-charging infrastructure. As yet, only small electric vehicles designed for specific purposes can compete in the market. The key issue are the batteries, which have a low energy density (about 1 percent of that of liquid fuel). This means that large batteries are needed to achieve an acceptable range, but these make the vehicle heavier, which in turn reduces fuel efficiency.

Electrically powered vehicles would have great potential if battery power could be increased substantially. The basic advantage over combustion engines is the comparatively simple technology and the avoidance of large quantities of exhaust heat. Battery power can be just as efficient as a combustion engine, depending on how the primary energy is generated. With the current energy mix, however, electric motors compare unfavourably in terms of energy consumption and CO_2 emissions. This conclusion is obviously different if renewable energy is used.

Although more advanced batteries are currently under development, a breakthrough leading to mainstream application of fully electric vehicles does not seem likely in the next 5 to 10 years.

B Examples of car models per market segment

Table 15 Market segmentation

Class	Segment	Examples	In this study included under category
A	Small	Smart, Suzuki Alto	Small cars
B	City	Fiat Punto, Mini	
C	Lower family	Renault Mégane, VW Golf	Medium-sized cars
D	Upper family	Citroën C5, Mazda 6	
E	Executive	Mercedes E-series, Volvo V70	Luxury cars
F	Lower luxury	Audi A8, BMW 7 series	
G	Lower sports	Alfa Romeo GTV, MG TF	Sports cars
H	Upper sports	Ferrari, Porsche	
I	Upper luxury	Rolls Royce, Maybach	Luxury cars
J	Medium MPV	Opel Zafira, Renault Scenic	MPV
K	Upper MPV	Renault Espace, Peugeot 807	
L	Utility	Jeep, Subaru Forester	SUV
M	Commercials	Ford Transit, Peugeot	Other

Source: (BOVAG / RAI)