



# EU Transport GHG: Routes to 2050?

## Cost effectiveness of policies and options for decarbonising transport

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20 November 2011 **Draft**

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# Executive Summary

## *Introduction*

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# Glossary<sup>1</sup>

BAU	Business as usual, i.e. the projected baseline of a trend assuming that there are no interventions to influence the trend.
BEV	Battery electric vehicle, also referred to as a pure electric vehicle, or simply a pure <b>EV</b> .
Biofuels	A range of liquid and gaseous fuels that can be used in transport, which are produced from biomass. These can be blended with conventional fossil fuels or potentially used instead of such fuels.
Biogas	A gaseous biofuel predominantly containing methane which can be used with or instead of conventional natural gas. Biogas used in transport is also referred to as <b>biomethane</b> to distinguish it from lower grade/unpurified biogas (e.g. from landfill) containing high proportions of <b>CO<sub>2</sub></b> .
Biomethane	Biomethane is the term often used to refer to/distinguish <b>biogas</b> used in transport from lower grade/unpurified biogas (e.g. from landfill) used for heat or electricity generation. Biomethane is typically purified from regular biogas to remove most of the <b>CO<sub>2</sub></b> .
CNG	Compressed Natural Gas. <b>Natural gas</b> can be compressed for use as a transport fuel (typically at 200bar pressure).
CO <sub>2</sub>	Carbon dioxide, the principal <b>GHG</b> emitted by transport.
CO <sub>2</sub> e	Carbon dioxide equivalent. There are a range of GHGs whose relative strength is compared in terms of their equivalent impact to one tonne of <b>CO<sub>2</sub></b> . When the total of a range of GHGs is presented, this is done in terms of CO <sub>2</sub> equivalent or CO <sub>2</sub> e.
DG TREN	European Commission's Directorate-General on Transport and Energy. This DG was split in 2009 into DG Mobility and Transport (DG MOVE) and DG Energy.
Diesel	The most common fossil fuel, which is used in various forms in a range of transport vehicles, e.g. heavy duty road vehicles, inland waterway and maritime vessels, as well as some trains.
EEA	European Environment Agency.
EV	Electric vehicle. A vehicle powered solely by electricity stored in on-board batteries, which are charged from the electricity grid.
FCEV	Fuel cell electric vehicle. A vehicle powered by a fuel cell, which uses hydrogen as an energy carrier.
GHGs	Greenhouse gases. Pollutant emissions from transport and other sources, which contribute to the greenhouse gas effect and climate change. GHG emissions from transport are largely <b>CO<sub>2</sub></b> .
HEV	Hybrid electric vehicle. A vehicle powered by both a conventional engine and an electric battery, which is charged when the engine is used.
ICE	Internal combustion engine, as used in conventional vehicles powered by petrol, diesel, <b>LPG</b> and <b>CNG</b> .
Kerosene	The principal fossil fuel used by aviation, also referred to as jet fuel or aviation turbine fuel in this context.
Lifecycle emissions	In relation to fuels, these are the total emissions generated in all of the various stages of the lifecycle of the fuel, including extraction, production,

<sup>1</sup> Terms highlighted in bold have a separate entry.

	distribution and combustion. Also known as <b>WTW emissions</b> .
LNG	Liquefied Natural Gas. <b>Natural gas</b> can be liquefied for use as a transport fuel.
LPG	Liquefied Petroleum Gas. A gaseous fuel, which is used in liquefied form as a transport fuel.
MtCO <sub>2e</sub>	Million tonnes of <b>CO<sub>2e</sub></b> .
Natural gas	A gaseous fossil fuel, largely consisting of methane, which is used at low levels as a transport fuel in the EU.
NGV	Natural Gas Vehicle. Vehicles using natural gas as a fuel, including in its compressed and liquefied forms.
NO <sub>x</sub>	Oxides of nitrogen. These emissions are one of the principal pollutants generated from the burning of fossil and biofuels in transport vehicles.
Options	These deliver <b>GHG emissions</b> reductions in transport and can be technical or non-technical.
Petrol	Also known as gasoline and motor spirit. The principal fossil fuel used in light duty transport vehicles, such as cars and vans. This fuel is similar to aviation spirit also used in some light aircraft in civil aviation.
PHEV	Plug-in hybrid electric vehicle, also known as extended range electric vehicle (ER-EV). Vehicles that are powered by both a conventional engine and an electric battery, which can be charged from the electricity grid. The battery is larger than that in an <b>HEV</b> , but smaller than that in an <b>EV</b> .
PM	Particulate matter. These emissions are one of the principal pollutants generated from the burning of fossil and biofuels in transport vehicles.
Policy instrument	These may be implemented to promote the application of the <b>options</b> for reducing transport's <b>GHG emissions</b> .
TTW emissions	Tank to wheel emissions, also referred to as direct or tailpipe emissions. The emissions generated from the use of the fuel in the vehicle, i.e. in its combustion stage.
WTT emissions	Well to tank emissions, also referred to as fuel cycle emissions. The total emissions generated in the various stages of the lifecycle of the fuel prior to combustion, i.e. from extraction, production and distribution.
WTW emissions	Well to wheel emissions. Also known as <b>lifecycle emissions</b> .

# 1 Introduction

## 1.1 Topic of this paper

This paper is one of a series of reports drafted under the *EU Transport GHG: Routes to 2050 II* project. This paper focuses on the cost effectiveness of both GHG reduction measures (both technical and behavioural ones) and policies. The scope of this paper has been limited to road transport because road transport is responsible for the largest share of GHG emissions in transport and has the best data availability on reduction options and policies. The discussion on cost effectiveness is based on a thorough review of the literature. For measures and options for which no quantitative figures are available, cost effectiveness are discussed in a qualitative way. Additionally, for the long term (up to 2050) only qualitative assessments of the cost effectiveness of GHG measures and policies are presented, since no reliable estimates of cost effectiveness figures are available for the long term (due to all kind of uncertainties, e.g. oil price developments).

This paper will be presented in draft form to a Focus Group meeting in November 2011. Based on the discussion at the meeting and possible comments and further evidence that will be received this paper will be updated.

## 1.2 The contribution of transport to GHG emissions

Transport is responsible for around a quarter of EU greenhouse gas emissions making it the second biggest greenhouse gas emitting sector after energy (see figure below). Road transport accounts for more than two-thirds of EU transport-related greenhouse gas emissions and over one-fifth of the EU's total emissions of carbon dioxide (CO<sub>2</sub>), the main greenhouse gas. However, there are also significant emissions from the aviation and maritime sectors and these sectors are experiencing the fastest growth in emissions, meaning that policies to reduce greenhouse gas emissions are required for a range of transport modes<sup>2</sup>.

While greenhouse gas emissions from other sectors are generally falling, decreasing 15% between 1990 and 2007, those from transport have increased by 36% in the same period. This increase has happened despite improved vehicle efficiency because the amount of personal and freight transport has increased.

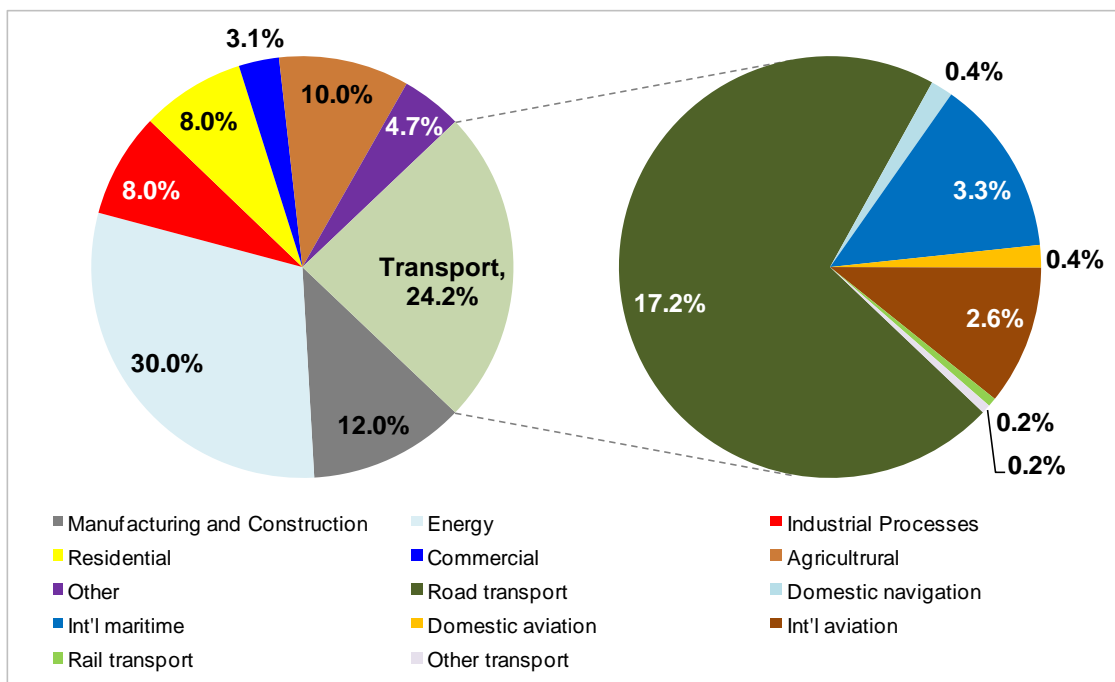
In the run-up to the Conference of the Parties of the UN Framework Convention on Climate Change in December 2009, the leaders of the EU's Member States called for significant reductions in global greenhouse gas (GHG) emissions:

*"The European Council calls upon all Parties ... to agree to global emission reductions of at least 50%, and aggregate developed country emission reductions of at least 80-95%... It supports an EU objective, in the context of necessary reductions according to the IPCC by developed countries as a group, to reduce emissions by 80-95% by 2050 compared to 1990 levels."<sup>3</sup>*

<sup>2</sup> EC DG Climate Action (2010): [http://ec.europa.eu/clima/policies/transport/index\\_en.htm](http://ec.europa.eu/clima/policies/transport/index_en.htm)

<sup>3</sup> *Presidency Conclusions*, Brussels European Council, 29/30 October 2009; see <http://register.consilium.europa.eu/pdf/en/09/st15/st15265.en09.pdf>

Figure 1.1: EU27 greenhouse gas emissions by sector and mode of transport, 2007



Source: EC DG Energy (2010)<sup>4</sup>

Notes: International aviation and maritime shipping only include emissions from bunker fuels

The key role that transport has to play in this long-term economy-wide aspiration was underlined by European Commission President Barroso in his *Political Guidelines for the next Commission*<sup>5</sup> where he emphasised the need to maintain the momentum towards a low carbon economy and towards decarbonising the transport sector in particular. In March 2010, the Commission, as part of its *Europe 2020 strategy*<sup>6</sup>, announced that it would make proposals to decarbonise transport, and in doing so linked the need to decarbonise transport with the wider sustainable growth agenda.

These high level political statements set the framework within which the original *EU Transport GHG: Routes to 2050* project was undertaken. One of the main aims of this project was to provide information and analysis to assist the Commission with its early thinking on a co-ordinated approach to reducing the GHG emissions of all modes of transport.

The increasing political importance that is being attached to decarbonising transport reflects the fact that, of all the economy's sectors, transport has proved to be one of the most problematic in terms of reducing its GHG emissions. As mentioned earlier, since 1990, GHG emissions from transport, of which 98% are carbon dioxide (CO<sub>2</sub>), had the highest increase in percentage terms of all energy related sectors<sup>7</sup>. Furthermore, transport's GHG emissions are predicted to continue to increase, without additional measures, to over 2,000 MtCO<sub>2</sub>e by 2050. This increase is shown in the next figure, with a split by mode of transport. The figure is an output from an Excel-based illustrative scenarios tool (IST) called SULTAN (**S**Ustainab**L**e **T**rANsport), which was developed under the previous project in order to identify the GHG reductions that transport could potentially deliver by 2050.

An increase of the order projected in the next figure would leave transport's GHG emissions 74% higher in 2050 than they were in 1990 (when the sector's emissions were nearly 1,200

<sup>4</sup> Based on historic data from DG Energy (2010) *EU energy and transport in figures Statistical Pocketbook 2010* Luxembourg, Publications Office of the European Union, 2010. Publication and data available for download at: [http://ec.europa.eu/energy/publications/statistics/statistics\\_en.htm](http://ec.europa.eu/energy/publications/statistics/statistics_en.htm)

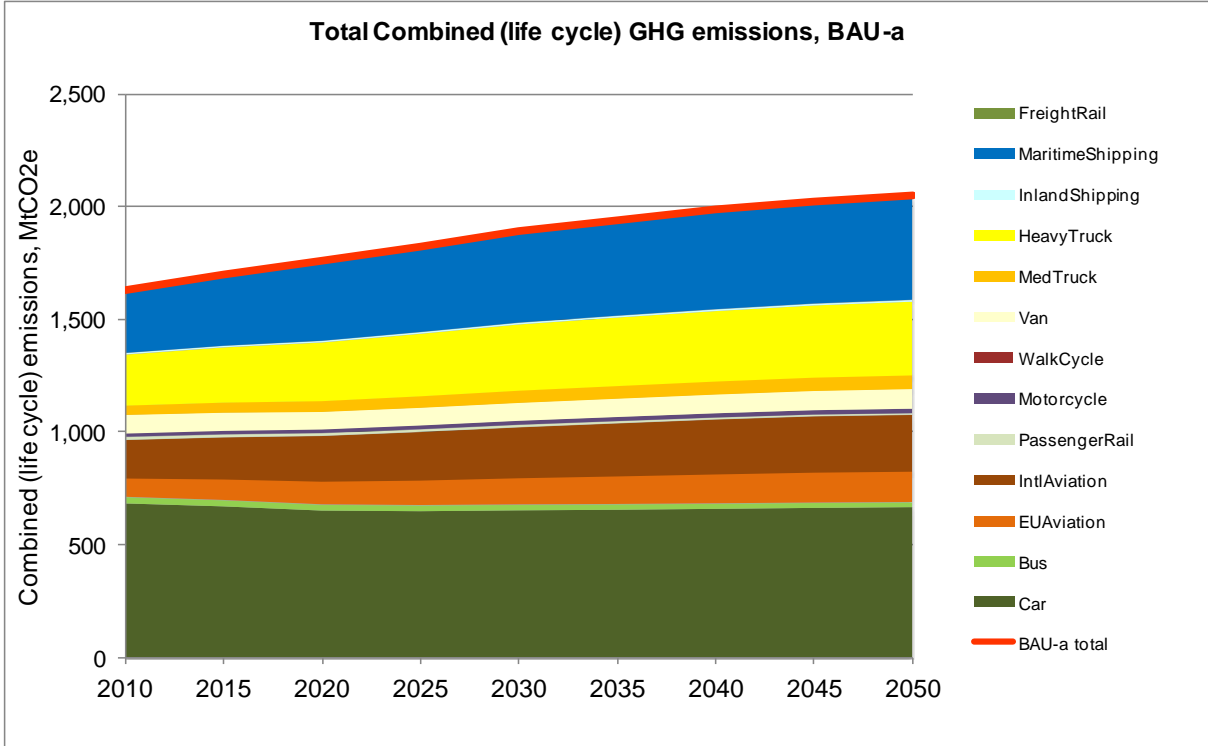
<sup>5</sup> Barroso, J (2009) *Political Guidelines for the next Commission*, September 2009, Brussels

<sup>6</sup> European Commission (2010) *Europe 2020: A strategy for smart, sustainable and inclusive growth* COM(2010)2020, Brussels 3.3.2020.

<sup>7</sup> DG TREN (2000) *Energy and transport in figures 2008-2009*

MtCO<sub>2</sub>e) and around 25% above 2010 levels. Significant emissions increases between 2010 and 2050 are projected for road freight (for which an increase of more than 45% is projected), aviation (more than 50%) and maritime (more than 65%) without additional policy instruments. Whilst GHG emissions from cars are still projected to contribute the most to the sector's GHG emissions in absolute terms in 2050, their emissions are projected to have declined slightly from 2010 levels, as anticipated improvements in the energy efficiency of vehicles negate projected increases in demand.

**Figure 1.2 Business as usual projected growth in transport's GHG emissions by mode**



Source: SULTAN Illustrative Scenarios Tool, developed for the EU Transport GHG: Routes to 2050 project

Notes: International aviation and maritime shipping include estimates for the full emissions resulting from journeys to EU countries, rather than current international reporting which only include emissions from bunker fuels supplied at a country level (which are lower).

The figure above shows the baseline, as projected by SULTAN. This is consistent with the range of results from other models and tools, although many of these only project to 2030<sup>8</sup>. Clearly, the predicted continued growth in the EU-27's GHG emissions from transport has the potential to prevent the EU meeting the long-term GHG emission reduction targets that the European Council supports, if no action is taken to reduce these emissions.

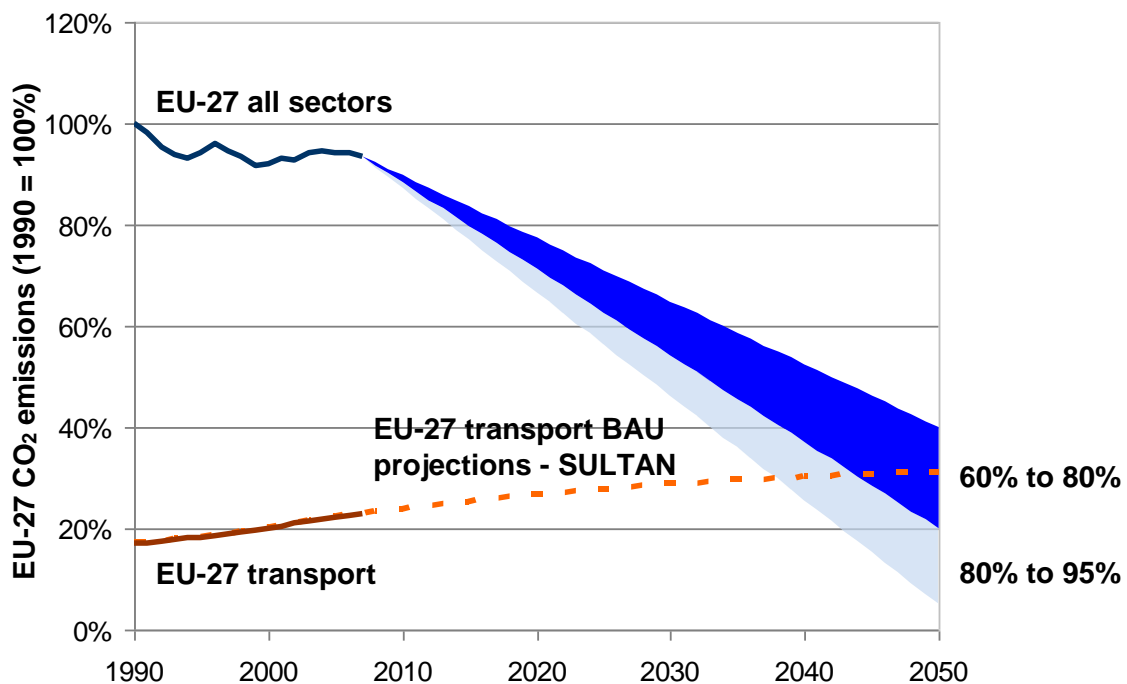
Figure 1.3 demonstrates that on current trends, transport emissions could be around 30% of economy-wide 1990 GHG emissions by 2050<sup>9</sup>. Whilst simplistic, in that it assumes linear reductions, the figure demonstrates that there is clearly a need for additional policy instruments to stimulate the take up of technical and non-technical options that could potentially reduce transport's GHG emissions. The EEA believes that all available policy instruments need to be used to achieve the ambitious GHG reduction targets<sup>10</sup>.

<sup>8</sup> See Appendix 19 SULTAN: Development of an Illustrative Scenarios Tool for Assessing Potential Impacts of Measures on EU transport GHG for details of the assumptions used and approach taken in the SULTAN Illustrative Scenarios Tool to projecting business as usual GHG emissions; also see <http://www.eurtransportghg2050.eu>

<sup>9</sup> The emissions included in this figure – for both the economy-wide emissions and those of the transport sector – include emissions from international aviation and maritime transport, in addition to emissions from “domestic” EU transport.

<sup>10</sup> EEA (2009) *Towards a resource-efficient transport system – TERM 2009: indicators tracking transport and environment in the European Union*, EEA Report No2/2010, Copenhagen.

Figure 1.3 EU overall emissions trajectories against transport emissions (indexed)



Source: EC DG Energy (2010) and SULTAN Illustrative Scenarios Tool<sup>11</sup>

### 1.3 Background to the project and its objectives

*EU Transport GHG: Routes to 2050 II* is a 15-month project funded by the European Commission's DG Climate Action and started in January 2011. The context of the project is still the Commission's long-term objective for tackling climate change. The scope of the first project was very ambitious, and the outputs from the study were very detailed and have already proved to be of great value to the European Commission and to industry, governmental and NGO stakeholders. However, there were a number of topic areas where it was not possible within the time and resources available for the study team to carry out completely comprehensive research and analysis. In particular, as the project evolved, both the study team and the Commission Services became aware that there were a number of themes and topic areas that would benefit from further, more detailed research. This new project is a direct follow-on piece of research to the previous *EU Transport GHG: Routes to 2050?* study, building on the research and analysis carried out for that study and complementing other work carried out for the latest Transport White Paper. In particular, the outputs from this new study will help the Commission in prioritising and developing the key future policy measures that will be critical in ensuring that GHG emissions from the transport sector can be reduced significantly in future years.

Therefore, the key objectives of the *EU Transport GHG: Routes to 2050 II* are defined as to build on the work carried out in the previous project to:

- Develop an enhanced understanding of the wider potential impacts of transport GHG reduction policies, as well as their possible significance in a critical path to GHG reductions to 2050.
- Further develop the SULTAN illustrative scenarios tool to enhance its usefulness as a policy scoping tool and carry out further scenario analysis in support of the new project;

<sup>11</sup> Projections based on data from the SULTAN Illustrative Scenarios Tool (BAU-a scenario) and historic data from DG Energy (2010) *EU energy and transport in figures Statistical Pocketbook 2010* Luxembourg, Publications Office of the European Union, 2010.

- Use the new information in the evaluation of a series of alternative pathways to transport GHG reduction for 2050, in the context of the 50-70% reduction target for transport from the European Commission's Roadmap for moving to a competitive low carbon economy in 2050<sup>12</sup>;

As before, given the timescales being considered, the project will take a quantitative approach to the analysis where possible, and a qualitative approach where this is not feasible. The project has been structured against a number of tasks, which are as follows:

- **Task 1:** Development of a better understanding of the scale of co-benefits associated with transport sector GHG reduction policies;
- **Task 2:** The role of GHG emissions from infrastructure construction, vehicle manufacturing, and ELVs in overall transport sector emissions;
- **Task 3:** Exploration of the knock-on consequences of relevant potential policies;
- **Task 4:** Exploration of the potential for less transport-intensive paths to societal goals;
- **Task 5:** Identification of the major risks/uncertainties associated with the achievability of the policies and measures considered in the illustrative scenarios;
- **Task 6:** Further development of the SULTAN tool and illustrative scenarios;
- **Task 7:** Exploration of the interaction between the policies that can be put in place prior to 2020 and those achievable later in the time period;
- **Task 8:** Development of a better understanding of the cost effectiveness of different policies and policy packages;
- **Task 9:** Stakeholder engagement: organisation of technical level meetings for experts and stakeholders;
- **Task 10:** Hosting the existing project website and its content;
- **Task 11:** Ad-hoc work requests to cover work beyond that covered in the rest of the work plan.

As in the previous project, stakeholder engagement is an important element of the project. The following meetings have been undertaken/are being scheduled:

- A large stakeholder meeting was held in on 29<sup>th</sup> June 2011 at which this new project was introduced to stakeholders, along with the presentation of interim results.
- A series of four Technical Focus Group meetings. The first two were held on 4<sup>th</sup> May 2011. The next two will be held on 28<sup>th</sup> November 2011..
- A second large stakeholder meeting at which the draft final findings of the project will be presented and discussed, anticipated to be held in February 2012.

As part of the project a number of papers will be produced, all of which will be made available on the project's website in draft and then final form, as will all of the presentations from the project's meetings.

<sup>12</sup> Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Roadmap for moving to a competitive low carbon economy in 2050, COM(2011) 112 final. Available from DG Climate Actions website at: [http://ec.europa.eu/clima/policies/roadmap/index\\_en.htm](http://ec.europa.eu/clima/policies/roadmap/index_en.htm)

## 1.4 Background and purpose of the paper

In developing climate policy, the cost effectiveness of measures is a key criterion. Since reaching sustainable levels of GHG reduction results in potentially high costs, minimising these costs is important to keep the EU economy competitive and to maximise welfare.

The key objective of this task is to gather evidence on the cost effectiveness of both GHG reduction measures (both technical and behavioural ones) and policies. Ideally a full set of cost effectiveness figures for the whole range of reduction options and policy options would be developed. However, within the scope of this task and given the lack of reliable and comparable data, this is not feasible. Especially with regard to behavioural reduction options and policy instruments the literature does provide less evidence on their cost effectiveness. For many of these options and instruments we therefore discuss the cost effectiveness in a qualitative way instead of presenting quantitative figures. Additionally, for all reduction options and policy instruments it holds that long term solid estimates for cost effectiveness figures are difficult to develop due to all kind of uncertainties (e.g. oil price developments). Due to these uncertainties no reliable estimates of cost effectiveness figures are available for the long term. Therefore, we only provide quantitative results for the period to 2030. With regard to cost effectiveness figures for the longer term (2050) a qualitative assessment is applied.

The scope of this paper has been limited to road transport because road transport is responsible for the largest share of GHG emissions in transport and has the best data availability on reduction options and policies.

In the previous project, a paper has been developed on the methodologies for assessing cost effectiveness (Davidson and Van Essen, 2009). One of the main conclusions from this paper was that the results from cost effectiveness assessment depend heavily on the methodologies used and departure points taken. Therefore the cost effectiveness figures from various studies are often difficult to compare (Anable and Bristow, 2007). However, by critically assessing the methodologies and assumptions used by the various studies, we try to explain the similarities and differences between the cost effectiveness figures presented by them. This may help to establish the strength of evidence on the sign and value of cost effectiveness figures for particular measures and policy instruments.

## 1.5 Structure of the paper

In the remainder of this paper we first briefly present the methodological framework for the assessment of cost effectiveness figures of GHG reduction measures and policies (chapter 2). In chapter 3 to 5 we discuss the evidence on cost effectiveness of technical and behavioural GHG reduction measures for road transport as well as GHG reduction policies. Finally, we present the conclusions of this paper in chapter 6.

## 2 Methodological framework

### Objectives:

The purpose of this sub-task was to:

- Develop a methodological framework for the assessment of cost effectiveness figures on GHG reduction measures and policies.

### Summary of Main Findings

⇒ Will be added to the final version of the paper

⇒

### 2.1 Introduction

In this chapter we present the methodological framework for this paper. First, we will briefly discuss the concept of cost effectiveness, mainly based on the paper on methodological issues concerning cost effectiveness as provided during the previous project (Davidson and Van Essen, 2009). Next to a discussion on the definition of cost effectiveness also some methodological issues affecting the size (and sign) of cost effectiveness figures are discussed. Finally, we will discuss the scope applied in this paper.

### 2.2 Defining cost effectiveness

The cost effectiveness of greenhouse gas abatement options is defined as the costs of an option divided by its greenhouse gas abatement potential, and is expressed in €, \$ or £ per ton of C (carbon) or CO<sub>2</sub> equivalents abated. For example, if an option abates 100 tonnes CO<sub>2</sub> and costs € 1,000 its cost effectiveness is € 10 per tonne CO<sub>2</sub>. Cost estimates typically include items as capital costs, operating and maintenance costs, and costs or benefits due to changes in fuel use. However, other items may be included as well, such as regulatory costs and the welfare costs related to changes in behaviour.

Two general approaches to calculate cost effectiveness figures are used. The first approach calculates cost effectiveness based on the CO<sub>2</sub> emission reduction and accompanying costs/benefits for a specific year (e.g. Blok, 2001; AEA, 2001; INFRAS, 2006). Therefore, the following formula is applied:

$$(1) \text{ Cost effectiveness} = \frac{I^{an} + \Delta_{O\&M} - \Delta_{\text{fuel costs}} - \text{secondary benefits}}{\text{annual CO}_2 \text{ emission abatement}}$$

In the formula  $I^{an}$  is the annuity of the total investment costs  $I$ :

$$I^{an} = I * \frac{(1+r)^l * r}{(1+r)^l - 1}$$

where  $l$  is the lifetime of the option,  $r$  the discount rate (generally 4% for calculating social costs) and  $I$  the total investment.

$\Delta_{O\&M}$  represents the additional annual operating and maintenance costs and  $\Delta_{fuel\ costs}$  the annual savings on fuel costs. The formula also includes monetised secondary benefits (e.g. cuts in air pollutant emissions through use of more efficient technology).

Another approach is to calculate the cost effectiveness based on total costs and benefits instead of annual costs and benefits (see e.g. TNO, 2006). In that case the following formula is used:

$$(2) \text{ Cost effectiveness} = \frac{I - NPV(\Delta_{lifetime\ O\&M}) - NPV(\Delta_{lifetime\ fuel\ costs}) - NPV(\text{sec. benefits})}{\text{Lifetime CO}_2 \text{ emission reduction}}$$

The results from both approaches could not be directly compared, since the results from the first approach are expressed in future values, while the results from the second approach are expressed in present values. A fuel cost saving of € 400 in 2015 has in 2011 a lower value (i.e. € 342 if we assume a discount rate of 4%), since there are some foregone interest payments since people receive these benefits not in 2011 but in 2015. Hence, the present value (value in 2011) of fuel saving benefits is lower than their future value (value in 2015). By the same kind of reasoning it holds that the present value of costs is higher than the future value. If we correct for this, by taking the present values from the annual benefits and costs in the first approach, the average of the annual cost effectiveness figures should be equal to the cost effectiveness figures found by applying the second approach. A further explanation is given in Box 1.

**Box 1: Applying different approaches for cost effectiveness calculations: an example**

Consider the following illustrative example: in 2011 a technical CO<sub>2</sub> abatement measure for passenger cars is implemented. The investment costs of this measure are equal to € 3500 and its lifetime is 10 years. Per year this measure results in fuel cost savings of € 400 and CO<sub>2</sub>-savings of 0.1 tonnes. To keep things simple, we assume no other operational costs or benefits (e.g. fewer air pollutant emissions). Finally, we assume a discount rate of 4%.

As mentioned in the main text, the cost effectiveness of this measure can be calculated using two approaches. First we calculate the cost effectiveness based on total costs and benefits over the lifetime of the measure. The input values needed for this calculation approach are: investment (€ 3,500), NPV of  $\Delta_{lifetime}$  fuel costs (€ 3,374) and lifetime CO<sub>2</sub> emission reduction (10 times 0.1 = 1 tonne). Based on these input values, the cost effectiveness is equal to € 126 per tonne CO<sub>2</sub> (expressed in 2011 values).

Second, the cost effectiveness calculation based on annual costs/benefits and effects. The annuity of the investment is equal to € 415, while the annual fuel cost savings is equal to € 400. Based on an annual CO<sub>2</sub> reduction of 0.1 tonne, we find that the cost effectiveness is equal to € 149 per tonne CO<sub>2</sub>. However, this value is based on future values and to compare this figure with the cost effectiveness figure based on the other approach a translation to present values is needed. Based on a discount rate of 4% the present values for the costs and benefits in future years are determined (for results, see table below). The resulting average cost effectiveness for the period 2011-2020 is equal to the figure based on the lifetime approach. For the separate years in the period 2011-2020 the cost effectiveness figures varies, which is the result of the depreciation method applied. It is possible to apply a depreciation method which results in constant cost effectiveness figures for all separate years.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
<b>Costs</b>											
Future values	415	415	415	415	415	415	415	415	415	415	415
Present values	415	399	384	369	355	341	328	315	303	292	350
<b>Benefits</b>											
Future values	400	400	400	400	400	400	400	400	400	400	400
Present values	400	385	370	356	342	329	316	304	292	281	337
<b>Cost effectiveness</b>											
Future values	149	149	149	149	149	149	149	149	149	149	149
Present values	149	144	138	133	128	123	118	113	109	105	126

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## 2.3 Some methodological issues

In the previous *EU Transport GHG: Routes to 2050* study a paper on methodological issues related to assessing cost effectiveness of climate change abatement options was published (Davidson and Van Essen, 2009). The main objective of this paper was to explain why studies to assess the cost effectiveness of policies and options addressing the climate impact of transport have yielded such widely different results. According to the analysis performed in this paper there are three issues with major impacts on the results:

- *Differences in perspective*; the cost effectiveness of an abatement measure can be assessed from the perspective of the end user or that of the society as a whole<sup>13</sup>. These perspectives do result in different cost effective figures due to the fact that 1) changes in tax revenues for the government are welfare impacts from a societal perspective, but are not taken into account in an end-user perspective, and 2) reductions in other externalities (e.g. due to a reduction in vehicle kilometres caused by the GHG policy measure) do affect overall welfare of the society and hence should be included from society's perspective but not from the end user's.
- *Differences in calculating direct expenditures*; a main element in cost effectiveness figures are the direct expenditures involved in implementing the abatement option(s) in question. These expenditures could differ between studies for several reasons:
  - Using factor costs vs. using market prices.
  - Baseline scenario and technology assumed. Since the effects and (additional) costs of an abatement technology (or policy) are compared to a baseline technology (or policy), the baseline scenario/technology assumed is crucial for the calculation of cost effectiveness figures. A key issue in assessing the cost effectiveness of transport climate abatement options is the assumed trend in the oil price adopted in the baseline scenario.
  - Assumptions on how costs develop over time; are learning effects and economies of scale included in the assessments?
  - Using ex ante vs. ex post cost estimates. The costs of an abatement option could be calculated prior to or after implementation. Ex post cost estimates are often lower than ex ante estimates, since the latter often underestimates economies of scale and learning effects, both leading to cheaper solutions.
  - Depreciation period or discount rate. Differences in depreciation periods or discount rates applied may also result in wide differences between cost estimates between studies.
- *Differences in including broad welfare impacts*; next to direct expenditures, the overall costs of an emissions abatement option also include broader welfare impacts. These broader welfare impacts may be indirect or not be expressed financially in any way (e.g. reduced welfare of people travelling less due to the implementation of a kilometre charging system). Also changes in the size of other externalities (e.g. accidents, air pollutants, noise) are welfare impacts that could be included in the calculation of cost effectiveness figures. Large differences exist between studies in the extent to which these broader welfare impacts are included in their cost effectiveness estimates. Also the way these costs/benefits are monetized (e.g. which shadow prices are used to monetize a change in air pollutant emissions?) differ between studies.

With regard to assessments of the cost effectiveness of policy instruments the cost effectiveness figures may also be heavily dependent on (Anable and Bristow, 2007):

- Assumptions about the behavioural response to measures, e.g. the assumed behavioural response to price signals (elasticity of demand).

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<sup>13</sup> Next to these two perspectives, also the perspective of the government could be used. However, this perspective is not often applied in studies estimating the cost effectiveness of GHG policy measures.

- The design of the instrument, e.g. applies a road user charge to all road users or only to passenger cars, is the road user charge revenue neutral or not, etc.
- The local/national context, e.g. are there high levels of congestion or not, is the area tightly or densely populated, etc. The local/national context affects particularly the size of possible external effects.

## 2.4 Scope of the paper

The analysis of cost effectiveness is in this paper based on a literature review. As mentioned before, not for all technical and behavioural options and policy instruments evidence on the cost effectiveness is available in the literature. Therefore we only present quantitative figures for options and policy instruments for which the literature present these kind of figures. For other options and instruments we only present a qualitative assessment of the cost effectiveness. Additionally, for the long run (2050) we only present a qualitative analysis of cost effectiveness of all options and policy instruments. In addition, the scope of this paper is limited to road transport

An important part of the *quantitative assessment* of cost effectiveness figures is a comparison of key methodological choices and assumptions made in the various studies. From previous studies (CE Delft, 2009; Davidson and Van Essen, 2009) it became clear that the size of cost effectiveness figures depend heavily on the methodologies and assumptions (e.g. on oil price, discount rate, etc) used (see section 2.3). Additionally, the welfare effects included in the cost effectiveness estimation may differ between studies (including broad welfare impacts or only financial costs, only first order impacts or also 2<sup>nd</sup> order impacts<sup>14</sup>, etc.). Based on the critical assessment of these underlying methodological choices and assumptions we try to explain differences between estimated figures and to come up with best estimates of (ranges of) cost effectiveness figures.

In the *qualitative assessment* of cost effectiveness figures we discuss the following issues:

- An overview of all (main) welfare impacts of the relevant technical/behavioural options and policy instruments. This includes direct expenditures, indirect effects, broader welfare impacts, and changes in other externalities.
- Where possible we also show whether the several welfare impacts can be expected to insignificant, significant or maybe even dominant.
- Where possible we will present some case studies, e.g. for policy instruments like fuel taxes and kilometre charges.

<sup>14</sup> Example of a second order effect of a more fuel-efficient passenger car: a more fuel-efficient car results in fuel savings and hence in less fuel tax revenues for the government. This loss in revenues could be compensated by the government by increasing another tax, e.g. income taxes. The distortive effects of this tax increase are an example of a second order welfare impact.

## 3 Cost effectiveness of technical options

### **Objectives:**

The purpose of this sub-task is to explore the cost effectiveness of technical options to reduce the CO<sub>2</sub> emissions of transport.

### **Summary of Main Findings**

⇒ Will be added to the final version of the paper

⇒

### 3.1 Introduction

In this chapter we discuss the cost effectiveness of technical options to reduce the CO<sub>2</sub> emissions of transport. We will both discuss the cost effectiveness of technical abatement options for passenger cars (section 3.2) and heavy duty vehicles (section 3.3). The cost effectiveness of biofuels will be discussed in section 3.4. In section 3.5 the conclusions of this section will be presented.

### 3.2 Passenger cars

#### 3.2.1 Overview of technical measures and costs at vehicle level

This section presents an overview of technical measures available to arrive at vehicle technology with a lower carbon footprint. For the short term it is quite clear what options are available to the manufacturers to arrive at lower CO<sub>2</sub> emissions. For the medium and long term (post 2020) there is a view of which development avenues are likely to be explored (such as electric drivetrains, fuel cells and metal-air batteries). Evaluation of cost effectiveness of these future technologies is much harder though, as uncertainties on potential, market and cost developments add up and prevent meaningful quantification. The report for the Low Carbon Vehicle Partnership in the UK [LowCVP(2011)] that was recently completed, gives a broader, total cost of ownership oriented assessment of the technologies that will be introduced coming years.

For further optimising fuel economy of cars with an internal combustion engine, a large array of possible measures to improve economy and hence deliver lower CO<sub>2</sub> emissions is available. The most promising categories are the optimisation of the engines themselves and hybridisation of the vehicles. In both categories the advantages to be gained are bigger for petrol cars than for diesel. The difference reflects the more advanced technologies already introduced in (on average) more costly diesel vehicles. In the short/ medium term the following fuel saving measures will be most notable in light-duty vehicles:

- *Engine options*: further refinement of existing ICE technology including: gas-wall heat transfer reduction, lower internal friction, cam phasing, direct injection, thermodynamic cycle improvements
- *Transmission options*, including optimisation of gear box ratios (downspeeding), automatic manual gearboxes, dual clutch gearboxes and CVT's
- *Hybridisation*, from start-stop systems to full hybrids
- *Driving resistance reduction*: weight reduction, aerodynamic improvements, lowering of rolling resistance and minimisation of driveline loss

- *Various others*, such as efficiency improvement in auxiliary systems and thermal management

### **CO<sub>2</sub> abatement costs of individual options**

Based on an evaluation of the data obtained from literature and from various stakeholders, a data set has been constructed by TNO and other consortium partners for the revision of regulation on CO<sub>2</sub> emissions from cars [TNO (2011)]. **This report has not been published yet.** It presents estimates of CO<sub>2</sub> reduction potential and additional costs (in 2010 Euros) of the various individual technologies at hand. These data, listed in Table 3.1 and Table 3.3 are used therein as input for the calculation of the average and distributional manufacturer costs of reaching the 2020 target of 95 g/km. The measures considered in that study do not include full electrification, since this is not so much a technology to be applied to existing cars with existing petrol or diesel engines, but rather a new powertrain technology for the longer term, and hence it is addressed separately in the overall approach of that study and also here .

The cost data presented in Table 3.1 and Table 3.3 are additional manufacturer costs for individual technologies applied to the 2002 reference vehicles (when CO<sub>2</sub> reduction technology had not started to penetrate the market), assuming large scale production at the moment the technologies are needed to meet the target. CO<sub>2</sub> reduction percentages are relative to the CO<sub>2</sub> emission of the 2002 baseline vehicle in each segment. Naturally some of these technologies have already been introduced since 2002 and will be introduced further for the purpose of achieving the 130 g/km by 2015 target, and hence the cost of the reduction to a 95 g/km average by 2020 is estimated in a more appropriate way as the difference between these two targets. It should be noted that the additional manufacturer costs do not represent the retail price increase.

The data on costs and reduction potentials of individual technologies as listed in Tables 3.1 and 3.3 are based on a review of data obtained from literature, in-house expertise from TNO and Ricardo and input submitted through questionnaires by ACEA, CLEPA and individual component manufacturers. Since a more extensive discussion can be found in the source report, and given the large number of options assessed in the study, numbers presented in Tables 3.1 and 3.3 will not be motivated in detail.

As can be seen from the list, the reduction potential for petrol cars, especially from engine-related options, is larger than for diesel vehicles. One of the main reasons for this is that through the introduction of direct injection, diesel vehicles have already made a significant step in fuel efficiency improvement in the period before 2002 while petrol vehicles are only now introducing direct injection in large scale

Moreover from the tables it can be observed that the costs for micro hybridisation are different for petrol and diesel. For petrol cars additional battery capacity needs to be installed to operate lighting, cabin ventilation, in car entertainment and other electrical equipment during vehicle stand still with the internal combustion engine stopped. Contrarily, diesel cars already have this capacity installed for glow plug operation, which is not needed for re-starting. Therefore this capacity can be utilized to power other electrical components during stand still. Besides additional battery capacity, a DC-DC converter is also needed to supply a steady voltage to said electrical components. This DC-DC converter is needed for petrol and diesel cars alike.

**Table 3.1: CO<sub>2</sub> reduction routes available and their costs for small and medium sized petrol cars. Reduction potential and the associated effectiveness/€ is given for applying that measure on its own.**

Improvement option	reduction potential [%]*	add-on cost [€]	□ [%/€]
Engine options	32	1255	0.0255
Transmission improvements	5	300	0.0167
Hybridisation, micro	7	375	0.0187
Hybridisation, mild	15	1450	0.0103
Hybridisation, full	25	2500	0.0100
Lowering driving resistance, medium WR	9	600	0.0150
Strong Weight Reduction	15	1200	0.0125
Other	15	610	0.0246

**Table 3.2: Example of stacking of various CO<sub>2</sub> emission reduction measures costs for small and medium sized petrol cars combined to arrive at higher overall reduction levels. Following order of stacking as given from top to bottom.**

Improvement avenue	reduction potential [%]*	add-on cost [€]	npv of fuel saved [€]	marginal reduction [%]**	Δg CO <sub>2</sub> /km**	marginal abatement cost per vehicle [€/tonne CO <sub>2</sub> ]	cumulative reduction % ref 2015
Engine options	32	1255	1405	32.0	40.5	-26.78	32.0
Others	15	610	448	10.2	19.0	61.72	42.2
Hybridisation, micro	7	375	176	4.0	5.1	281.36	46.2
Transmission improvements	5	300	119	2.7	4.7	281.85	48.9
Lowering driving resistance, medium WR	9	600	202	4.6	7.3	395.59	53.5

**Table 3.3: CO<sub>2</sub> reduction routes available and their costs for small and medium sized diesel cars. Reduction potential and the associated effectiveness/€ is given for applying that measure on its own.**

Improvement option	reduction potential [%]*	add-on cost [€]	η [%/€]
Engine options	11.5	550	0.0209
Transmission improvements	4	300	0.0133
Hybridisation, start stop	4	200	0.0200
Hybridisation, mild	11	1450	0.0076
Hybridisation, full	22	2500	0.0088
Lowering driving resistance, medium WR	7.5	560	0.0134
Strong Weight Reduction	14.5	1100	0.0132
Others	14	610	0.0230

**Table 3.4: Example of stacking of various CO<sub>2</sub> emission reduction measures costs for small and medium sized diesel cars combined to arrive at higher overall reduction levels. Following order of stacking as given from top to bottom.**

Improvement avenue	reduction potential [%]*	add-on cost [€]	npv of fuel saved [€]	marginal reduction [%]**	Δg CO <sub>2</sub> /km**	marginal abatement cost per vehicle [€/tonne CO <sub>2</sub> ]	cumulative reduction % ref 2015
Others	14	610	1163	14.0	17.9	-112.88	14.0
Engine options	11.5	550	822	9.9	12.6	-78.47	23.9
Hybridisation, start stop	4	200	253	3.0	3.9	-49.65	26.9
Lowering driving resistance, medium WR	7.5	560	455	5.5	7.0	54.67	32.4
Transmission improvements	4	300	225	2.7	3.5	79.76	35.1

\*reduction potential is given as an absolute percentage in fuel consumption decrease. As various measures are stacked in order to arrive at higher efficiencies, the effective reduction potential of second, third etc. measures becomes diluted as the total amount of fuel consumed (or CO<sub>2</sub> emitted) already decreased because of earlier applied measures.

\*\* Thus, the following order in which various measures are applied influences their effective reduction potential (relative to the baseline). The baseline in this calculation is the expected 2015 values (kilometres weighted average of 126.7 g CO<sub>2</sub>/km for the small and medium petrol segment, and 127.7 for diesel). The measures assumed to be already implemented by the manufacturers to arrive at given emission levels (representing a 22.3 and 13.3 % reduction from the 2002 reference level), are variable valve actuation, gas-wall insulation, low friction design, down-speeding, low rolling resistance tyres and aerodynamic optimisations for petrol, and mild downsizing, combustion optimisation, down-speeding, low rolling resistance tyres and aerodynamic optimisations for diesel respectively.

### CO<sub>2</sub> abatement costs for going from 130 g/km in 2015 to 95 g/km in 2020

The current regulatory landscape sets out a trajectory of reduction of CO<sub>2</sub> emissions of ICE-driven vehicles, and hence fuel consumption, towards 2015 (target 130 g/km) and 2020 (target 95 g/km). To put these estimates into perspective based on currently observed average emission levels, those emissions can be assumed to decrease by an average of around 30% between 2010 and 2020.

The increasing fuel economy of the cars represents a net saving through fuel that will be less consumed over the expected economic lifetime of the vehicles. This was calculated in the tables above assuming an effective economic lifetime of a vehicle of 20 years in which on average 7590 (petrol) or 13295 (diesel) litres of fuel are consumed. The effective discount rate is 4 % in the base calculation. Further, the assumed fuel price developments (excluding excise duties and VAT) are for petrol: € 0.658, 0.777, 0.891 and 1.010 for the years 2015, 2020, 2025 and 2030 respectively. For diesel the corresponding figures are € 0.727, 0.854, 0.973 and 1.092 respectively. The fuel price projections are based on “EU energy Trends to 2030” and correspond to oil prices of \$72/boe (2010), \$88/boe (2020) and \$106/boe (2030). For the period after 2030 an extrapolation was used. In order to give an impression of fuel price and depreciation sensitivity, the following exercise was done. The cost effectiveness of the 135 to 95 g/km measure for an average petrol and ditto diesel cars was calculated in five different scenarios:

- 1) Base scenario: 27 % overall reduction in fuel consumption of new cars, with above given fuel prices, and 4 % / year discount rate. The reduction percentage is the same as reducing CO<sub>2</sub> emissions from 130 to 95 g/km.
- 2) As 1, but with fuel prices starting at the same point, but linearly rising to double the end price (€ 2.258 and € 2.422 in 2035 respectively). Discount rate at 4% / a.
- 3) As 1, but fuel prices starting at the same point and linearly decreasing to half the end price (€ 0.505 and € 0.546 in 2035 respectively). Discount rate at 4% / a.
- 4) Fuel price scenario as 1, but discount rate at 8% / a.
- 5) Fuel price scenario as 1, but discount rate at 2% / a.

**Table 3.5: Net cost effectiveness of going from the expected EU-27 2015 situation to the 95 g/km target for petrol and diesel cars (all segments) in five different scenarios with respect to fuel price and discount rate assumptions.**

	Petrol cars			Diesel cars		
	Additional vehicle costs [€]	npv petrol saved [€]	abatement cost [€/ tonne CO <sub>2</sub> ]	Additional vehicle costs [€]	npv diesel saved [€]	abatement cost [€/ tonne CO <sub>2</sub> ]
base	1465	1243	48.09	1314	2158	-98.46
fuel *2	1465	1649	-39.76	1314	2853	-179.53
fuel /2	1465	1040	92.02	1314	1810	-57.92
interest *2	1465	951	111.19	1314	1658	-40.12
interest /2	1465	1445	4.24	1314	2505	-139.00

For the petrol segment, the EU-27 2015 → 95 g/km reduction, means an emission reduction of 27.4 %, and for the diesel segment of 24.8 %. The costs of technical measures necessary to realize the reductions, are approximated using the cost effectiveness curve presented in the SR-1 study.

### Vehicle size increase versus light-weighting

On top of technical measures, there are a couple of trends that appear to have opposite effects. On one hand there is an autonomous growth of the size and weight of cars due to economic growth and preference of the public for ever increasing vehicle sizes. This size increase leads to a mass increase (and most often an increase in aerodynamic drag as well) which, of course, leads to higher fuel consumption per kilometre driven.

On the other hand there is a trend toward using lightweight construction, for example composite windows, body panels or magnesium and aluminium alloys. Which of the two trends will have a stronger influence on fuel efficiency development in the longer run is difficult to predict. Possibly they counteract so that effectively no change will follow from these two combined, OR either of the two becomes dominant and a decrease or increase in power consumption per kilometre will follow.

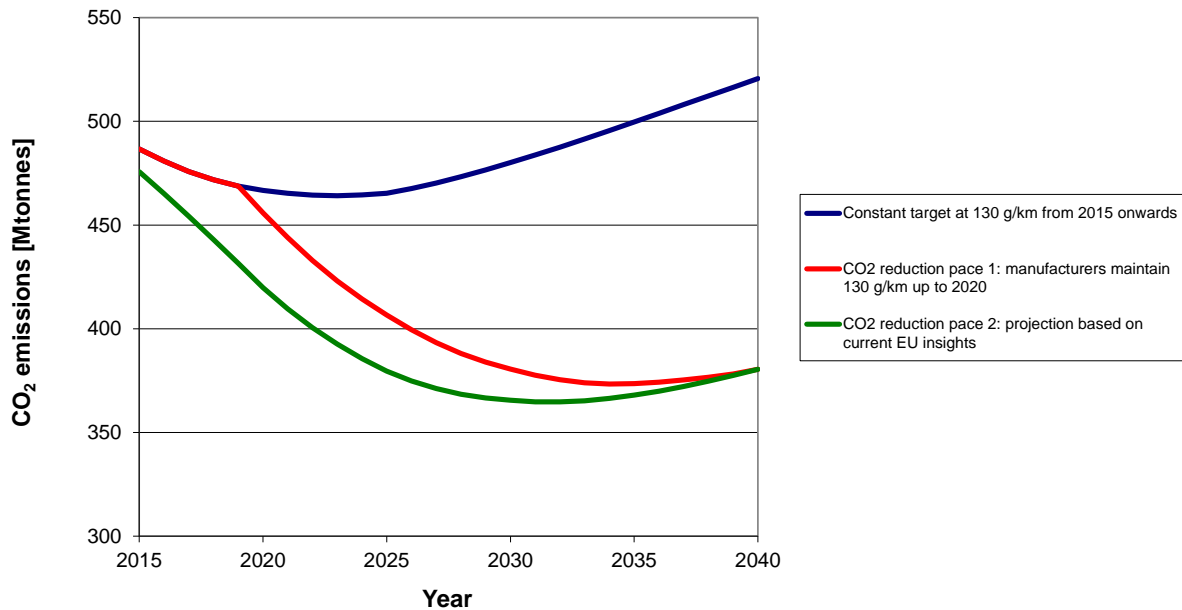
Due to the uncertainty of the future developments with regard to vehicle mass, also the social costs of CO<sub>2</sub> reducing technologies related to traffic safety – which depends among other things on the mass differences between vehicles – are uncertain.

### 3.2.2 Cost effectiveness on the short and medium term, at fleet level

In order to provide a first-order approximation of the cost-effectiveness of the 95 g CO<sub>2</sub>/km fleet average emissions Regulation [EC regulation (2009)], an estimate was made of the EU-27 fleet emissions between 2015 and 2040 in three scenarios:

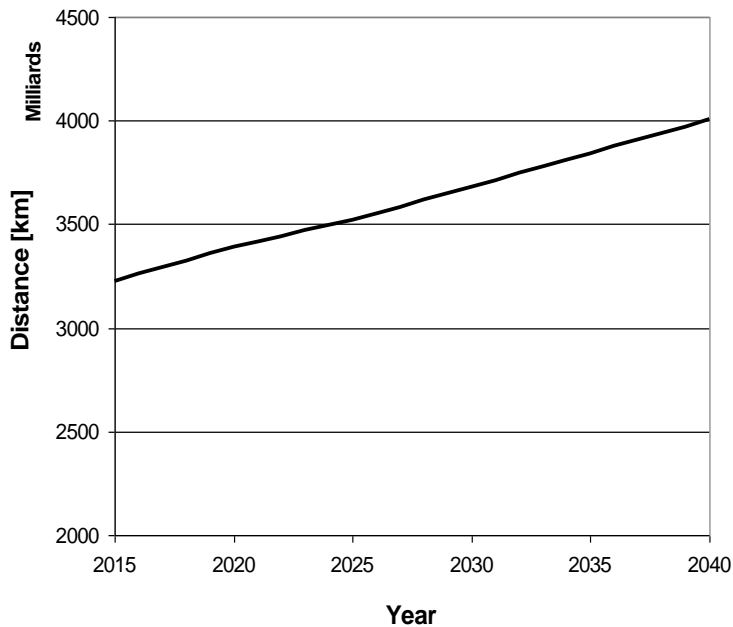
- *BAU*: maintaining a 130 g CO<sub>2</sub>/km new sold cars average from 2015 onwards
- *Reduction pace 1*: as above until 2019, after which the new sold cars average becomes 95 g CO<sub>2</sub>/km in a single step
- *Reduction pace 2*: based on currently estimated averages, the overall EU27 fleet average would be ~147.5 g/km by 2015 and ~124 g/km by 2020 (based on the current estimates that the new sold cars average in EU27 would be around 120 and 95 g/km in 2015 and 2020 respectively).

**Figure 3.1: Road Traffic CO<sub>2</sub> emissions from 2015 assuming various levels of CO<sub>2</sub> emissions of new cars being added to the existing fleet.**



The increase at the right hand end of the graph reflects the assumed increase in total distance travelled by the fleet as a whole [TREMOVE source data SR-1, TNO (2011)]. The overall distance travelled is further given in the figure below.

**Figure 3.2: Projected total distance travelled by the EU-27 fleet as a whole.**



In order to obtain estimates for fleet-wide costs of CO<sub>2</sub> reduction, the cost curves that were obtained in service request 1 of the “Vehicle Emissions” framework [TNO (2011)] were used. These so called cost curves relate to the costs presented in table 1 and 2 in the sense that the curves try to approximate the less costly combination of measures to arrive at a certain reduction in fuel consumption. These costs are input to a first-order approach to the overall cost effectiveness of CO<sub>2</sub> emission abatement. The cost curves show quickly increasing

slopes towards higher reduction potentials and hence the present approach should serve as an indication for comparative purposes only.

Taking into account the difference in total emissions between the 130 g/km “BAU” scenario and the “95 g/km from 2020” scenario, and the costs at the vehicle level which are estimated to reach the necessary CO<sub>2</sub> reductions, one arrives at the following results:

**Table 3.6: Cumulative costs in relation to abated CO<sub>2</sub> (having deducted the savings of fuel not used).**

Scenario 1			Scenario 2		
Cumulatively abated CO <sub>2</sub> (Mtonnes)	Cumulative costs (G€)	abatement costs (€/ tonne CO <sub>2</sub> )	Cumulatively abated CO <sub>2</sub> (Mtonnes)	Cumulative costs (G€)	abatement costs (€/ tonne CO <sub>2</sub> )
1896	10	6	2342	10	4

- In scenario 2 the average emission levels are gradually lowered to the foreseen regulatory levels. The costs for these measures being introduced in anticipation, are shared by manufacturer and buyers. Here only the regulatory costs (based on the cost curves in the SR1, Cars & CO<sub>2</sub> work) have been taken into account.
- All cumulative costs in the above have been translated to a net present value in 2020 using a discount rate of 4% (similar to method used in REMOVE)

These results depend on the assumed service life time of the vehicle. In fact, these estimates are based on the assumption that vehicles sold in 2020, the first year of the 95 g/km Regulation, will stay on the road (with decreasing yearly mileages) until 2040. Hence, within the scenario outlined for this exercise, by 2040 the whole fleet will consist of vehicles sold under this Regulation.

It should be added that in addition to the potential for ICE-driven vehicles to reduce their CO<sub>2</sub> footprint significantly (through an average 30% improvement in energy expenditure by 2020), usage of high-blend biofuels could drive further reductions. It is important though to note that biofuels have their own specific issues that make it difficult to simply assume a further CO<sub>2</sub> reduction. Biofuels and its problems are discussed in detail in the biofuels chapter (section 3.4). After 2020, however, further engine efficiency improvements are limited and relatively costly, while the amount of biofuels that will be available may be limited.

### 3.2.3 Cost effectiveness on the longer term

The longer term evolution is difficult to assess due to uncertainties in how the markets will develop. A significant part of the 2050 fleet may have an electric drivetrain. The storage system (batteries or fuel cells on H<sub>2</sub>, metal or even bio-ethanol) is difficult to predict at this time and will depend on developments of factors like costs and capacity. Some industry insider reports by Valentine-Urbschart and Bernhardt (2009), McKinsey (2010) and Duleep et al. (2011) provide the following estimates for electric drivetrains and fuel cells:

#### Electric drivetrains

For light duty vehicles the first series of electric vehicles are being introduced in the market. The present revival of electric vehicles is based on lithium ion battery technology. This technology will quite likely be the driver for a definite breakthrough of electric vehicles. The major disadvantages of battery electric vehicles are twofold: 1) limited specific energy, making it **heavy** to carry sufficient energy to ensure a range comparable to ICEs and 2) the battery technology is still relatively costly, which makes it **expensive** to carry sufficient energy. For the time being the add-on cost of the technology is some 100% higher than that of the conventional petrol vehicle. In the long run cost efficiency will likely increase. For batteries for example a price drop of approximately 80% is foreseen by industry insiders between 2010 and 2020. In 2010 the price level was ~870 €/kWh, which was forecast to drop to ~460 €/kWh (2015), ~300 €/kWh (2020) and arrive at ~175 €/kWh by 2050. Cost estimates given in “Impacts of Electric Vehicles” (Duleep et al., 2011) are somewhat comparable,

predicting a battery production cost of about 750-800 €/kWh in 2010, dropping to about 630 €/kWh in 2012, 320-360 €/kWh in 2020 and around 200 €/kWh in 2030. As these are production cost, the actual cost to car manufacturers and then to consumers will be higher.

The size of the energy storage in a specific car is to some degree a design freedom of the manufacturer. In order to enable a minimally acceptable driving range and vehicle performance, the battery size needed for a small car is ~16 kWh, for a medium sized car ~24 kWh and for a large car ~36 kWh. In as far as specific energy of the batteries is concerned, some improvements are possible as well, but most estimates don't go much above 30% capacity increase. New (breakthrough) technologies may change this in a couple of decades, though.

For the time being there is the (major) uncertainty on realistic lifetime predictions for the batteries. The lifetime of batteries is an important factor for cost effectiveness because of the amortisation applicable for the electric vehicle. This will probably become less of an issue if and when batteries indeed appear as reliable in the field as they were on the manufacturers' test-benches. As a matter of fact recent signs in the market are very promising in this regard. The 'normal' hybrid Toyota Prius has rarely (if ever) shown battery lifetime problems, and it has been on the market for 14 years. Furthermore, OEMs are lowering the list prices for spare battery packs, and are introducing extended warranty periods (e.g. 10 years) for the battery pack. Of course these policies will have a marketing commercial background, but clearly the OEMs would not do this if they were not confident that the majority of the battery packs will indeed survive. Finally, quick charging and even Vehicle-to-Grid services are being introduced on the market (e.g. by Nissan) in the first generation Li-ion electric cars already. A couple of years ago, this technique seemed unlikely to be introduced commercially soon, but still, it is happening already. Also the Vehicle-to-Grid service option may be partly manufacturer bravura, but again, the industry would not offer it if there were major uncertainties behind it. All these signs indicate that the OEMs are confident about the long time reliability and performance of the technology even in its present immature state.

Moreover, the investment costs for a charging infrastructure that will feed the electric vehicles must be taken into account. There will be consequences for the electric power grid, where locally larger demands on power transmission capacity may come up once the (local and visiting) numbers of electric vehicles grow. The costs associated with modifications of the power grid are dependant on whether there is spare capacity available or not at the beginning. In many cases reinforcement will not be necessary if the residual power capacity available late at night and in the morning are put to use for recharging (a so-called smart grid). Further the recharging points themselves will demand an investment. In the low power version for charging in the private domain, the investment costs are modest (tens up to hundred euro per recharging point), but if charging is foreseen in the public domain, costs go up to around € 1000 per charging point.

Next to all the uncertainties on the costs of electric cars, also uncertainty on the CO<sub>2</sub> reduction potential does exist. Here a lot is dependant on whether the marginal extra electric power required for feeding the fleet of electric cars will be generated in a fossil, nuclear or sustainable energy power plant. The extraordinary tank to wheel efficiency of electric vehicles will be nearly offset in terms of CO<sub>2</sub> impact if coal-powered electricity is used. On the other hand, most other electric energy mixes will give a real CO<sub>2</sub> reduction potential, but this is of course dependant on the precise mix going into the grid.

## **Fuel cells**

Fuel cell technology will likely become more attractive as energy generator in the coming decade. McKinsey (2010) projects a price drop from ~500 €/kW (2010), to ~110 €/kW in 2015, to arrive at ~45 €/kW in 2020 for hydrogen fuel cells. For the distribution of hydrogen a whole new infrastructure must be installed however and the societal costs for this hydrogen

distribution net are not included. Metal-air batteries, which are another category of fuel cells, hold the promise of reaching higher power densities and lower costs compared to the hydrogen fuel cell.

### 3.3 Heavy duty vehicles

#### 3.3.1 Overview of technical measures

##### Measures to lower aerodynamic or rolling resistance

For trucks there are quite a few options to start reducing tailpipe CO<sub>2</sub> emissions with technological measures that are readily available, and can be fitted onto new as well as existing heavy duty vehicles. The measures act on improvement of aerodynamics and lowering of rolling resistance.

**Table 3.7: Measures for lowering driving resistance on heavy goods vehicles.**

Measure	Short description
Low rolling resistance tyres	Tyres with enhanced rubber composition and tread optimized for lower rolling resistance.
Aerodynamic fairings	A variety of measures such as cab fairing, wind dam (below front bumper), collars narrowing the gap between cabin and trailer and side skirts, aimed at lowering wind drag from truck, or tractor trailer combination.
Spray reduction Mud-flaps	Mud flaps as normally mounted behind the wheels, that are perforated and pass some riding wind. This breaks the wind drag pattern behind the flap, and thereby lowers aerodynamic drag.
Aerodynamic trailers	A complete reworking of trailers into a rounder, more tear-like overall aerodynamically streamlined form.

##### Diesel engine optimization

For the medium term also a further development of existing diesel engines will be seen. Here internal friction and recovery of waste energy will enable a significant improvement in overall engine efficiency. The possibilities for efficiency increase in the combustion engines are summarized in Figure 3.3.

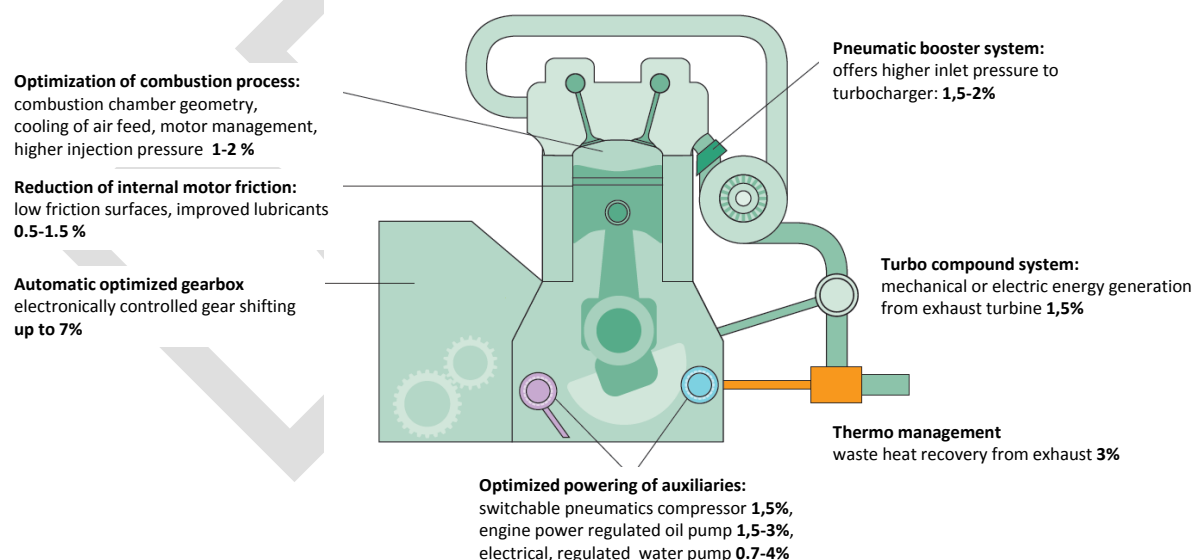
**Table 3.8: An overview of possible measures in the diesel engines and their potential.**

Measure	Short description
Turbocompound (mech. / elec.)	A turbine in the exhaust gas flow that mechanically or electrically recuperates energy from the gas stream. Energy efficiency improvement in both cases is around 1.5 %.
Thermo management	Recovery of waste heat from the exhaust in a heat exchanger. Can improve efficiency of the engine by 3%.
Automated Transmissions	Robotized gearbox that enables faster and more efficient gear shifting. Possible efficiency gain up to 7%.
Combustion systems	Combination of enhanced hydrodynamic form of the combustion chamber, fuel injection systems and inlet air systems, all helping a more complete and efficient combustion. CO <sub>2</sub> benefit 1-2%
Lower engine friction	Combination of low friction internal engine surfaces and improved lubricants. Can save between 0.5 and 1.5% fuel.
Variable pumps / compressors	Variable flow oil pump, Air compressor and pneumatic booster system as well as variable flow water pump. Various CO <sub>2</sub> reduction potential

\* In percent, compared to incumbent technology (not complete vehicle)

The present generation of engines can accept up to some 10 % of biofuels. For higher percentages, a reworking or adaptive mechanism should be present in the engines in order to be able to accept higher concentrations of biofuel. The possibilities for CO<sub>2</sub> reductions with biofuels are handled in a separate chapter.

**Figure 3.3: Estimated efficiency potential of various technical measures that can be taken on Heavy Duty diesel engines. (Source: Shell LKW studie 2030 (2010))**



The references Shell (2010), Roland Berger (2009) and TNO (2011) were used as input for effectiveness as well as cost level estimates in this section.

### 3.3.2 Cost effectiveness on the short and medium term

Indicative improvements of CO<sub>2</sub> emissions are given in the table below (reference year 2009). Apart from the references mentioned in the previous paragraph also Ricardo (2009),

AEA-Ricardo (2011) and TNO (2011) were taken into account. Where data in mentioned sources were based on expert estimates, the data were averaged in order to level out differences between individual sources (which were modest anyway).

**Table 3.9: CO<sub>2</sub> reduction potential for a typical medium duty (MD) heavy goods vehicle (~ 12 tonnes). Reduction potential and the associated effectiveness/€ is given for applying that measure on its own.**

Improvement option	reduction potential [%]*	add-on cost [€]	η [%/€]
aerodynamic cab fairing	3	285	0.0105
spray reduction mud flaps	1.5	25	0.0600
low rolling resistance tyres	4	0	1.0000
automated transmission	8	2100	0.0038
variable pumps /compressors	6	1300	0.0046
various engine options	12	6000	0.0020
hybridisation start-stop (MD)	3	550	0.0055
mild hybrid (MD urban)	15	10000	0.0015
full hybrid (MD)	18	20000	0.0009

**Table 3.10: Example of stacking of various CO<sub>2</sub> emission reduction measures costs for a typical medium duty (MD) heavy goods vehicle (~ 12 tonnes), combined to arrive at higher overall reduction levels. Following order of stacking as given from top to bottom.**

Improvement option	reduction potential [%]*	add-on cost [€]	npv of fuel saved [€]	marginal reduction [%]**	Δg CO <sub>2</sub> /km**	marginal abatement cost per vehicle [€/tonne CO <sub>2</sub> ]	cumulative reduction % ref 2015
hybridisation start-stop (MD)	3	550	752	3.0	9.4	-68.52	3.0
variable pumps /compressors	6	1300	1459	5.8	18.2	-27.77	8.8
automated transmission	8	2100	1828	7.3	22.8	37.90	16.1
various engine options	12	6000	2523	10.1	31.4	351.54	26.2

\* Reduction potential given as absolute percentage relative to 2009 reference situation.

\*\* Effective reduction given as percentage relative to 2015. This level is 7.9 % lower than 2009 reference.

Fairings, anti-spray mud flaps and low rolling resistance tyres are assumed to be applied standard to achieve this.

**Table 3.11: CO<sub>2</sub> reduction potential for a typical heavy duty (HD) heavy goods vehicle (approx. 40 tonnes). Reduction potential and the associated effectiveness/€ is given for applying that measure on its own.**

Improvement option	reduction potential [%]*	add-on cost [€]	η [%/€]
aerodynamic fairings	7	4200	0.0017
spray reduction mud flaps	1.5	25	0.0600
low rolling resistance tyres	4	180	0.0222
automated transmissions	8	2700	0.0030
variable pumps /compressors	6	1600	0.0038
diesel engine options	12	8000	0.0015
hybridisation full hybrid (urban)	18	28000	0.0006

**Table 3.12: Example of stacking of various CO<sub>2</sub> emission reduction measures costs for a typical heavy duty (HD) heavy goods vehicle (~ 40 tonnes), combined to arrive at higher overall reduction levels. Following order of stacking as given from top to bottom.**

Improvement option	reduction potential [%]*	add-on cost [€]	npv of fuel saved [€]	marginal reduction [%]**	Δg CO <sub>2</sub> /km**	marginal abatement cost per vehicle [€/tonne CO <sub>2</sub> ]	cumulative reduction % ref 2015
variable pumps /compressors	6	1600	6274	6.0	47.8	-189.11	6.0
automated transmissions	8	2700	7863	7.5	59.9	-166.68	13.5
aerodynamic fairings	7	4200	6330	6.1	48.2	-85.41	19.6
diesel engine options	12	8000	10091	9.7	76.8	-52.61	29.2
hybridisation full hybrid (urban)	18	28000	13321	12.7	101.4	279.75	42.0

\* Reduction potential given as absolute percentage relative to 2009 reference situation.

\*\* Effective reduction given as percentage relative to 2015. This level is 5.3 % lower than reference. Anti-spray mud flaps and low rolling resistance tyres are assumed to be applied standard to achieve this.

## Hybridisation

Hybridised Heavy duty vehicles are slowly entering the market in limited numbers. Specifically for services where many stops are made, the technique has excellent potential for reducing CO<sub>2</sub> emissions of the vehicles. Examples: city buses or refuse collection vehicles. Mild to full hybrid trucks will certainly become economically attractive in the longer run, but extra costs prohibit application to those types of vehicles that can benefit most, which would be city type trucks (like mentioned city buses, refuse collection vehicles and city distribution trucks). In table 8 it can be seen that (with present insights) a full hybrid Heavy Duty vehicle will not return the extra investment in fuel savings. In the longer run though, when component cost have dropped and component performance has increased, much broader use of hybrid drivelines will be likely.

### 3.3.3 Cost effectiveness on the longer term

#### Hybrid drivetrains using bio-fuels

The combination of fully hybridised drivelines and use of second generation biofuels appears to be a good opportunity for sustainable heavy goods transport in the long run. Also in terms of cost effectiveness this combination might actually win over electric drivetrains. This is largely attributable to the much higher specific energy of liquid fuels (fossil, bio and synthetic alike) compared to batteries or even fuel cells (although future technological breakthroughs may change this view). Actually the high specific energy argument counts for heavy duty road transport just as much as for aviation.

#### Electric drivetrains

At this point in time there is only small hope for large scale deployment for electric vehicles in the heavy duty segment. The current and foreseeable developments in battery technology give room for medium duty vehicles (up to some 12 tonnes GVW). As an example Roland Berger (2010) produces an electric vs ICE TCO calculation of a 12 tonnes truck, and arrives at a projected 2% benefit of opting electric for the 2020 situation. For the really heavy duty segment though, the energy density appears to be too low to be a realistic alternative to diesel and hybrid. In the longer run this might change with alternative

batteries and fuel cells (be it hydrogen or metal-air technology) which promise much higher energy densities. At present too little is known to make a useful extrapolation of technology efficiency with regard to cost efficiency for CO<sub>2</sub> emission abatement.

For the moment it is unclear whether the required energy densities will be reached with new battery or fuel cell technology. For medium duty vehicles there exist pre-series and for example Mercedes Benz is introducing the electric Vito, and Renault the electric Midlum. For the time being the add-on costs of the technology are some 100% higher than that of the conventional diesel vehicle. In the long run cost effectiveness will likely increase. For batteries for example a price drop of approximately 80% is foreseen by industry insiders between 2010 and 2020. As explained in the chapter on passenger cars, there is the uncertainty regarding possible lifetime problems for the batteries. This will probably become less relevant if and when batteries indeed appear as reliable in the field as they were on the manufacturers' test-benches.

## **3.4 Biofuels**

Biofuels is a term for a range of fuels for the transport sector, including vegetable oil, biogas/biomethane, bioethanol, biomass-to-liquid (BtL) biodiesel, hydroprocessed vegetable oil (HVO) biodiesel and conventional biodiesel. Biofuels can theoretically save significant levels of greenhouse gas emissions (Hill et al., 2009). However, recent evidence on the Indirect Land Use Change (ILUC) effects of biofuels have changed drastically the view on the GHG abatement potential of these fuels. ILUC relates to the consequence of releasing more carbon emissions due to indirect land use changes around the world. This is induced by the fact that pristine lands are cleared and converted to new cropland, in order to produce the crops for feed and food that were diverted elsewhere to biofuels production. These emissions may be very significant, depending on the type of crop used for the biofuel production, but they are more difficult to quantify than the direct emissions of the biofuels. ILUC could also negatively affect biodiversity (EP 2011, EC 2010).

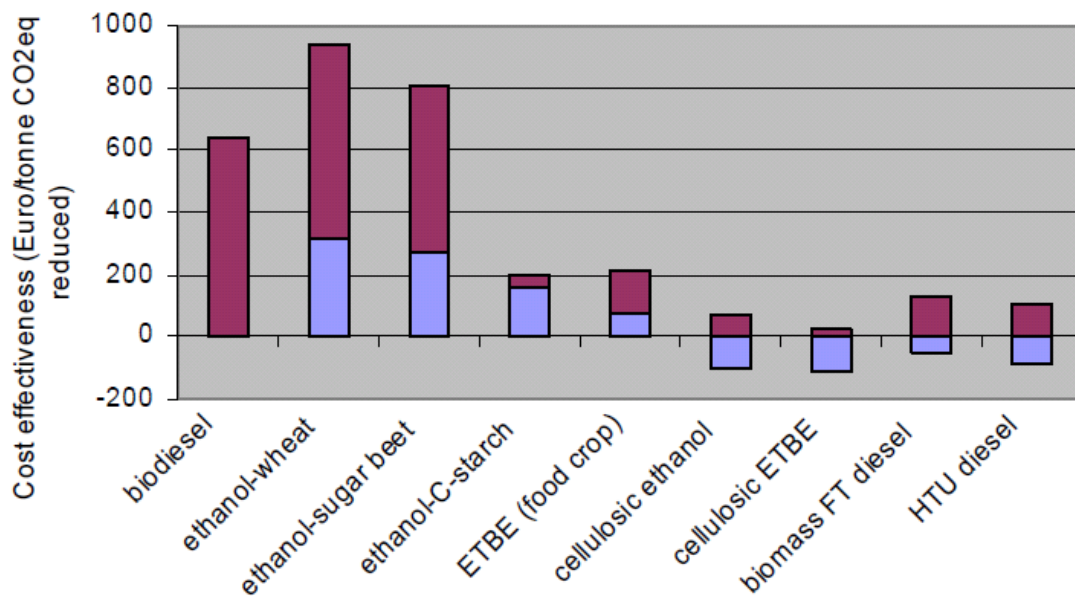
The calculated values of the cost effectiveness of biofuels have changed drastically in recent years. Due to inclusion of Indirect Land Use Change effects (ILUC effects), the effectiveness of biofuels has decreased significantly. In this section, we will first briefly discuss studies excluding the ILUC effect. After this, we will discuss the cost effectiveness of biofuels including the recent insights on the ILUC effects.

### **3.4.1 Cost effectiveness excluding ILUC effects**

Various studies have determined the cost effectiveness of biofuels excluding ILUC effects. Studies often referred to are CE Delft (2005), TNO et al (2006) and CONCAWE (2007).

CE Delft (2005) determines the cost effectiveness of biofuels based on a large number of literature sources (see Figure 3.4). The figures are calculated based on the costs of petrol and diesel by September 2005. Information on cost elements included are not available.

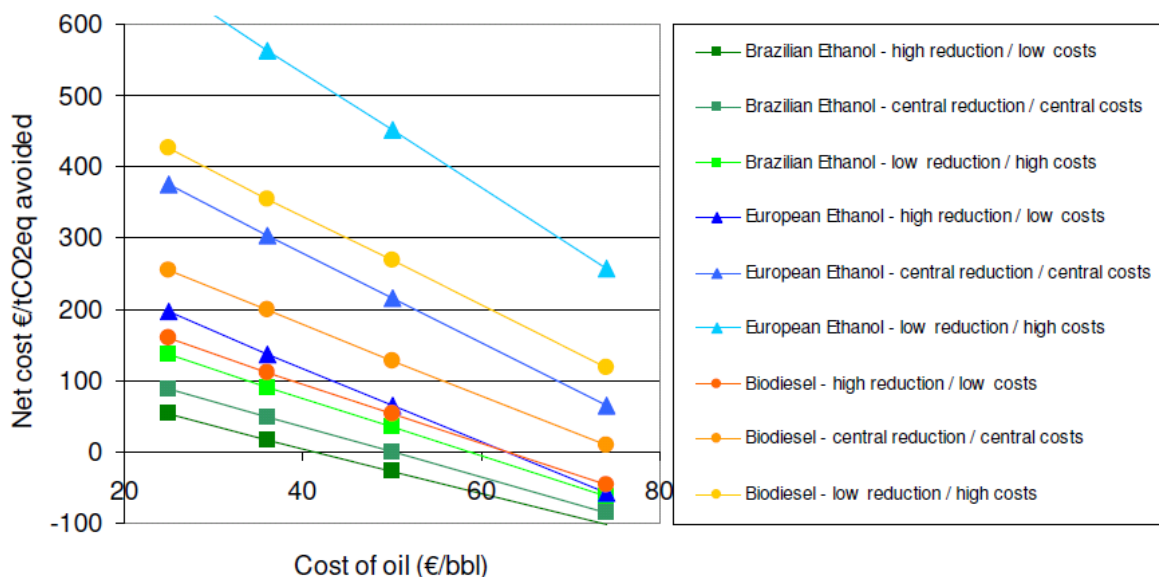
**Figure 3.4 Cost effectiveness of GHG reduction of various biofuels**



Note: The red bars indicate the spread in data (i.e. blue bar is lower bound of the range in cost effectiveness figures)

TNO et al. (2006) present cost effectiveness figures which are more or less in the same order of magnitude as calculated in CE Delft (2005). For biodiesel, a range of 47 € /tonne to 426 € / tonne is calculated. For Brazilian ethanol the range is -103 € / tonne to 136 € /tonne and for European ethanol the range is -58 € / tonne to 656 € / tonne. The spread in results is caused by differences in assumptions for production cost, reduction % of the biofuels and the oil price. The strong dependency of the cost effectiveness figures on production costs and oil price is illustrated in Figure 3.5:.

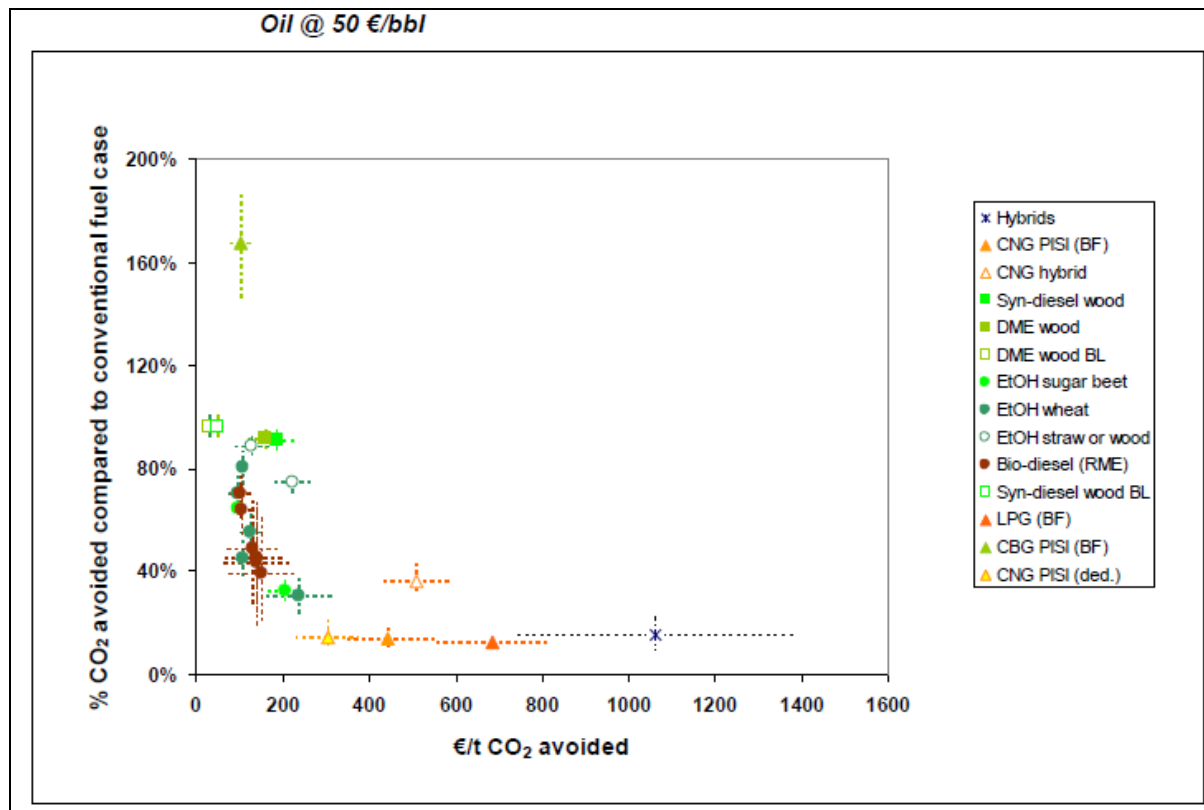
**Figure 3.5: Cost effectiveness of biofuels as function of production costs and oil price**



Also Concawe (2007) presents cost effectiveness figures of biofuels that are in the same order as the ones presented by CE Delft (2005) and TNO et al. (2006). The main results of this study are presented in Figure 3.6, where the cost effectiveness for various biofuels is shown in relation to the CO<sub>2</sub> reduction (in %). The study shows a cost effectiveness for

conventional biofuels in the range of 150-300 €/t (oil price 25 €/bbl) and 100 -200 €/t (oil price 50 €/bbl).

Figure 3.6: GHG abatement costs of biofuels and other alternative fuels



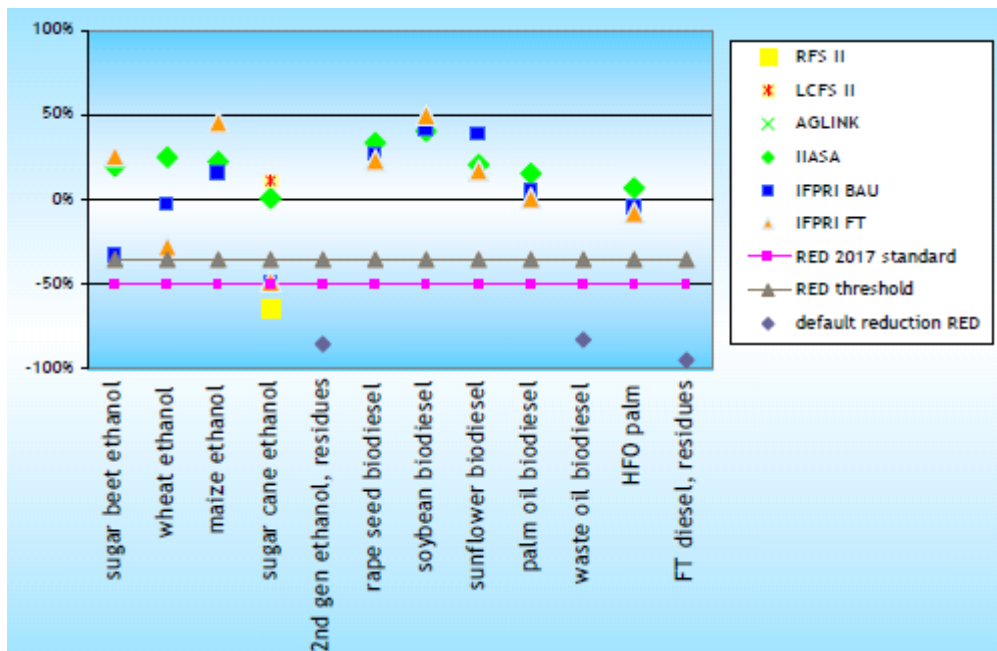
Although the results of the studies differ, in general the order of magnitude is more or less comparable (relatively high values). In general, the abatement costs for conventional biofuels are estimated in the range of € 100 to € 300 per tonne CO<sub>2</sub>. As discussed before, a major drawback of these studies is that the ILUC effects have not been taken into account. We have therefore decided not to carry out a more detailed comparison of these results (in terms of cost effectiveness) in this study.

### 3.4.2 Cost effectiveness including ILUC effects

Recent insights show that for many biofuels the emission of greenhouse gases may increase rather than decrease when incorporating the ILUC effect, although the range of the modelling results is still significant. To illustrate this effect, the net greenhouse gas effect of incorporating the ILUC effect, for various biofuels and calculated by different models, is presented in the following Figure 3.7.

The figure shows on the vertical axis the percentage of greenhouse gas reductions of biofuels compared to conventional fuels, when incorporating the ILUC effect for the biofuels. The horizontal axis presents various current biofuels. The results are based on various agro-economic models (see legend) which simulate global agricultural markets, trade, intensification, possible crop replacements and so on. The reductions of the Renewable Energy Directive (RED) standard 2017, the Renewable Energy Directive threshold and the default reduction in the Renewable Energy Directive are presented in the figure as well (see lower three in legend).

**Figure 3.7: Net GHG emission reduction of various biofuels (compared to fossil fuels), taking ILUC emissions into account**



Source: CE (2010a)

The figure demonstrates that most of the models predict a net increase of greenhouse gases, when incorporating the ILUC effect for biodiesel. For these biofuels, determining the cost effectiveness in terms of € / tonne CO<sub>2</sub> reduction makes therefore no sense anymore. For most types of ethanol, the outcomes of the models differ in terms of a net positive or negative effect, making it at least doubtful to determine one specific cost effectiveness value.

### 3.4.3 Cost effectiveness on the longer term

The challenge for the longer term is to develop biofuels that are more cost effective than the current generation. Promising concepts seem to be the development of biofuels from waste and other 'rest streams'. These biofuels are currently under development and have not been implemented widely on a commercial scale yet. Specific projections on cost effectiveness figures are to our knowledge not available yet.<sup>15</sup>

## 3.5 Conclusions

The assessments carried out in this chapter shows that various technical options with negative abatement costs are available for road transport for the period until 2020. The number of cost effective technical options for heavy duty vehicles is larger than for passenger cars, but the reduction potential of these options are significantly lower. The assessment on cost effectiveness of technical options on passenger cars shows that the shift to cars with CO<sub>2</sub> emission figures of 95 g/km could be realized in a cost effective way. On the longer term electric and hybrid (for HGVs) drivetrains may be promising options to further decrease the climate impact of road transport. However, studies on these options show wide ranges in CO<sub>2</sub> impacts and costs. Therefore, reliable estimates of the cost effectiveness of these options could not be provided yet. Finally, recent studies on the abatement potential of biofuels show that due to the ILUC effects many biofuels will result in a net increase of GHG emissions. Therefore, it is not possible (and useful) to determine cost effectiveness values for this option.

<sup>15</sup> Source: Information Mrs Kampmann. Biofuels expert CE Delft.

## 4 Cost effectiveness of behavioural options

### **Objectives:**

The purpose of this sub-task is to explore the cost effectiveness of behavioural options to reduce the CO<sub>2</sub> emissions of transport.

### **Summary of Main Findings**

⇒ Will be added to the final version of the paper

### 4.1 Introduction

In this chapter we will discuss the cost effectiveness of behavioural measures in the field of transport. Behavioural measures include (CE Delft et al., 2011):

- Buying and using smaller cars;
- Buying and using electric or plug-in hybrids;
- Applying a fuel efficient driving style;
- Sharing a car;
- Changing transport modes;
- Teleworking;
- Applying visual meetings;
- Make (more) use of e-commerce;

To our knowledge, for most behavioural measures no quantitative estimations of cost effectiveness figures exist. Only for the appliance of a fuel efficient driving style these kinds of figures are available (see section 4.2). The cost effectiveness of the other behavioural measures will be briefly discussed in a qualitative way in section 4.3.

An important element in the assessment of cost effectiveness figures of behavioural mitigation options are the so-called 'broad welfare impacts'. In a simplistic financial view, behavioural measures, such as buying a smaller car, sharing a car, travel by bike instead of car, or teleworking, will save (fuel) costs and therefore result in negative abatement costs. However, this approach does not take into account the negative welfare loss caused by the unintended behaviour. For example, car users prefer to travel by car instead of by bike and hence a shift to the bike will result in a reduction of their personal welfare. In assessing the cost effectiveness of behavioural measures, these kinds of 'broad welfare impacts' should be taken into account, in order to avoid too optimistic cost effectiveness figures. Furthermore, the cost effectiveness figures should ideally take co-benefits, like a reduction in congestion or air pollution, into account.

### 4.2 Cost effectiveness figures of applying a fuel-efficient driving style

Applying a fuel efficient driving style (eco-driving) is the only behavioural measure in the transport field for which cost effectiveness figures are available. Eco-driving is the name often given to driving techniques that drivers can use to optimise their car fuel economy. According to research by the Energy Saving Trust, 36% of drivers would consider paying approximately €60 for a two-hour eco-driving lesson, if this were to pay for itself in fuel savings within 8 months. According to the researchers, this is a realistic period for a typical

car and private driver (EST, 2005). On a European wide level, the European Climate Change Programme calculated a reduction potential of Eco-driving of at least 50 million tons of CO<sub>2</sub>-emissions in Europe by 2010, saving about € 20 billion (Ecodrive, 2011). These results indicate that Eco-driving is a measure with low abatement costs. In this section we discuss the results of three studies considering the cost effectiveness of eco-driving: TNO et al (2006), CE Delft (2008) and Ecofys (2006).

#### 4.2.1 Cost effectiveness Eco-driving calculated in TNO et al (2006)

TNO et al (2006) finds that the assessment of fuel-efficient driving, in terms of CO<sub>2</sub> and cost savings, is extremely sensitive to the methodology used and to variations in the values of the input parameters. According to the authors, especially the level and duration of the effect (which have large uncertainty margins) affect the outcome. Unfortunately, the study doesn't provide sensitivity analyses for the impact of these parameters.

The following cost and benefits are included in this study:

- Costs for driving lessons
- Costs for Installation Gear Shift Indicators (GSI)
- Costs of government campaigns to promote fuel efficient driving
- Fuel saving benefits

Possible co-benefits are not taken into account by TNO et al. (2006).

Table 4.1 shows the costs effectiveness figures calculated by TNO et al. (2006) for various levels of oil prices. These figures show the cost effectiveness of eco-driving from a societal perspective and are calculated for the average new vehicle in 2008, which is assumed to emit 140 gCO<sub>2</sub>/km on the Type Approval test.

**Table 4.1: GHG abatement costs**

Scenarios for appliance of eco-driving	GHG abatement costs (€ tonne CO <sub>2</sub> eq., at different fuel prices <sup>16</sup> )			
	€ 0.21/l	€ 0.30/l	€ 0.41/l	€ 0.60/l
Incorporation eco-driving in lessons for new drivers	-35	-50	-69	-100
Eco-driving lessons for existing drivers	-2 to -23	-21 to -42	-45 to -66	-85 to -106
Installation Gear shift indicators (GSI)	-26	-50	-78	-128
Lessons for existing drivers + GSI	-7 to -21	-26 to -40	-49 to -63	-89 to -103

The table shows a negative cost-effectiveness for all scenarios of applying eco-driving. The figures are comparable for most scenarios. As may be expected, the cost effectiveness of the various scenarios for applying eco-driving increase by increasing fuel prices.

To estimate the cost effectiveness of eco-driving, TNO et al. (2006) used a lot of assumptions. The key ones are:

- The long term effect of fuel-efficient driving (taught in lessons) results in a reduction of 3%. This result could be increased to 4.5% with the aid of GSI;
- The duration of these effects is assumed to be 40 years for new drivers and 25 years for existing drivers;
- The costs of lessons are assumed to be € 50 - €100 for existing drivers; for new drivers no additional costs are assumed, as the fuel efficient driving is taught during regular driver training.
- The additional manufacturer costs of GSI are €15 (€22 additional retail price).

<sup>16</sup> The fuel prices correspond to the following oil prices: € 25/bbl, € 36/bbl, € 50/bbl, € 74/bbl

- Abatement costs were calculated on a societal cost basis (excl. tax) as additional vehicle costs minus the net present value of the lifetime fuel cost savings, divided by the lifetime well-to-wheel CO<sub>2</sub> emission reduction. The discount rate used was 4%.

#### 4.2.2 Cost effectiveness eco-driving calculated in CE Delft (2008)

CE Delft (2008) assessed the effects and cost-effectiveness of the Dutch Eco-driving programme. This programme involve the integration of eco-driving principles in driving school curriculum for new drivers, subsidizing training courses for groups of (professional) drivers, extensive promotional campaigns (television, radio, websites, leaflets), tax exemptions and promotion campaigns for in-car devices and facilitating optimal tyre pressures.

CE Delft (2008) estimate the societal cost-effectiveness of the Dutch eco-driving programme at -€ 45 per tonne (price level 2007). The following assumptions are used to estimate this figure:

- Costs included: costs of training courses, costs of communication instruments, fuel cost savings.
- Costs of in-car devices are not taken into account.
- A fuel-price of € 0.41 per litre (excl. taxes) was assumed.
- No information on discount rate applied is reported.

#### 4.2.3 Conclusion

The results form TNO et al. (2006) and CE Delft (2006) are in the same range. Depending on the fuel price the cost effectiveness of eco-driving broadly ranges from - €10 to -€100 per tonne CO<sub>2</sub>. This implies that eco-driving is probably a behavioural measure with negative societal abatement costs from the perspective form the society (and the end-user). The presented cost-effectiveness figures may be even a (slight) underestimation of the actual figures, since co-benefits are not included in both studies. Possible co-benefits of eco-driving are:

- A reduction of traffic noise. For example, the engine noise of a car driving with 4000 revolutions per minute (rpm) equals the engine noise of 32 cars driving at 2000 rpm. Shifting the gear up early may therefore result in significant noise reduction<sup>17</sup>.
- Enhanced driving skills and increased road safety<sup>18</sup>.
- According to the Ecodrive project ([www.ecodrive.org](http://www.ecodrive.org)), eco-driving may reduce local air pollution (NO<sub>x</sub>, SO<sub>2</sub>, PM, VOC). However, in CE Delft (2007) it is argued that there is no effect on other pollutants. Applying the instructions in an incorrect manner could even increase the emissions of other pollutants.

In the long run the cost effectiveness of fuel efficient driving will probably decline. The CO<sub>2</sub> effect of eco-driving will become smaller in future years, since future vehicles will become more energy efficient by applying fuel efficiency improvements (TNO, 2009), while the costs of eco-driving courses and campaigns will probably stay equal.

### 4.3 Qualitative assessment of cost effectiveness of some other behavioural measures

Next to applying a more fuel-efficient driving style consumers could apply various other behavioural changes to reduce the CO<sub>2</sub> impact of their travel behaviour. For these

<sup>17</sup> Source: [www.ecodrive.org](http://www.ecodrive.org)

<sup>18</sup> CANON COMPANY in Switzerland trained the ECO-DRIVING style with 350 service car drivers in VSZ VELTHEIM. The drivers reduced fuel consumption by 6.1%, had 22% more km per accident and 35% less accidents in total. Source: [www.ecodrive.org](http://www.ecodrive.org)

behavioural options no quantitative estimations of cost effectiveness figures are available. Therefore we will perform a qualitative assessment of the cost effectiveness of some main behavioural measures.

#### **4.3.1 Buying a more fuel-efficient car**

Consumers could reduce the climate impact of their car travel by buying a more fuel-efficient car. In this paper we consider two types of this behavioural change:

- buying a smaller car;
- buying an electric or plug-in hybrid car.

The purchase of a smaller car provides consumers various financial benefits: lower purchase costs, lower energy costs, lower maintenance costs and lower insurance costs (CE Delft et al., 2011). On the other hand, there are various non-financial costs related to the purchase of smaller cars: consumers prefer larger cars over smaller ones, since large cars are more practical and safe and they have preferable symbolic advantages (e.g. better image). Moreover, small cars may challenge the mobility-related habits of people (since a small car restricts people in their flexibility due to the fact that they can transport less luggage/people).

Empirical evidence on the size of the non-financial costs is not available. Finally, a large scale shift to smaller cars may improve the traffic safety, which is a welfare improvement from a societal perspective. Based on the findings presented above, we expect that on average the non-financial costs of small cars are larger than the financial benefits plus co-benefits (increased traffic safety), since consumers' preferences for large cars are rather strong (indicated by increasing average car sizes over time). This results in positive cost effectiveness figures. Due to expected fuel price increases in the future, it may be expected that the cost effectiveness of buying a smaller car will increase.

The purchase of an electric or plug-in hybrid car will result in higher financial costs for consumers. CE Delft et al. (2010) show that the total cost of ownership (TCO) of electric and plug-in hybrid cars is significantly higher than for conventional cars. The currently relative high TCO of electric/hybrid cars are assumed to reduce over time, but will probably stay higher than for conventional cars in the period up to 2030. It should be mentioned, however, that these TCO figures depend heavily on some external variables, like energy prices. A large increase in fuel prices, for example, may improve the competitiveness of electric and hybrid cars. Next to the financial costs associated with the purchase of electric and plug-in hybrid cars, also non-financial costs should be considered. According to CE Delft et al. (2011) the purchase of electric/hybrid cars may negatively affect consumers' welfare, since they prefer conventional cars over electric/hybrid ones (since the latter perform worse compared to conventional cars, consumers doubt the reliability and safety of the car, soft image of electric/hybrid cars, etc.). Finally, electric/hybrid cars may have some welfare enhancing co-benefits, like lower noise levels and less air pollution. Due to the relatively high financial and non-financial cost of electric/hybrid cars, the cost effectiveness of the purchase of these cars may be rather low. The cost effectiveness may increase over the years, as investment costs are expected to decrease. Furthermore, also the non-financial costs may decrease over the years, if positive experiences of initial users of electric/hybrid cars may increase the confidence of consumers with respect to these cars.

#### **4.3.2 Modal shift**

Changing modes could be an effective measure to reduce the CO<sub>2</sub> impact of passenger transport. However, this behavioural measure provides also some costs to the traveller. If people shift from the car to the bike, this results in lower financial (user) costs. For a shift to public transport the impact on financial (user) costs depends heavily on the local context and

hence couldn't be estimated in general. In both cases, also non-financial costs exist: since people prefer to travel by car a shift to alternative modes will result in a welfare loss. Due to a lack of knowledge on the size of the various welfare impacts of a modal shift, it is not possible to predict the sign of the cost effectiveness of this behavioural option. It should be mentioned that both the cost effectiveness of a shift to public transport and a shift to the bike depends heavily on external variables (e.g. fuel prices) and trip characteristics (e.g. trip length).

Modal shift measures could also be used to reduce the CO<sub>2</sub> impact of freight transport. A shift from road transport to rail or inland waterway transport (IWT) could result in fewer CO<sub>2</sub> emissions. General figures on the cost effectiveness of these kinds of shifts are not available. Due to the rational character of freight transport, it may be expected that the most cost effective possibilities for adapting a mode shift are applied. However, in reality many shippers do not behave completely rational and hence it may be possible to some cost effective opportunities for modal shifts are still available. Further research in this area is needed.

### 4.3.3 Teleworking

The climate impact of commuter travel could be reduced if people would work (more often) at home. The CO<sub>2</sub> impact of this behavioural change will be larger if it's applied by more people. According to CE Delft et al. (2011) the maximum realistic mitigation potential<sup>19</sup> of teleworking is equal to 6-8% of the CO<sub>2</sub> emissions of passenger transport.

Teleworking results in various (negative) costs, which size depends heavily on the scale on which teleworking is applied:

- *Lower mobility costs*; since teleworkers travel fewer kilometres than non-teleworkers, the travelling costs (both fuel and other variable costs) will decrease.
- *Changes in energy costs for heating, air conditioning and electricity*; teleworking may increase energy use at home, but, on the other hand, reduces the amount of energy used at the office. The overall impact of teleworking on the energy use at the office and at home depends heavily on the extent teleworking is applied in firms. If a significant number of people work from home for 3-4 days a week, firms could reduce their energy use significantly, especially by reducing their office space. In this case the impact on total energy use will be negative. However, if the take-up of teleworking is lower, the opportunities for energy saving at the office are smaller and hence could be lower than the additional energy demand at home.
- *Lower costs due to smaller offices*; on the long term firms with a high level of teleworkers could reduce their office space and sublet some space to other firms or move to smaller (and cheaper) locations.
- *Fewer parking places necessary at the office*; if teleworking is applied on a large scale firms could reduce the number of parking places at the office.
- *Increased productivity of teleworkers*; several studies (Ecofys, 2009; Sustel, 2004) show that employees who work at home regularly become more productive, due to lower absenteeism, longer working hours which are not claimed, and a better environment to work concentrated.
- *Broad welfare impacts for teleworkers*; teleworking could improve or deteriorate the perceived working satisfaction of employees. The possibility to combine their job in a more efficient way with their personal life is for many employees a welfare enhancing aspect of teleworking. Also the time saved in commuter traffic is a positive welfare impact of teleworking. However, on the other hand, some people may fear social isolation or adverse impacts on their careers if they work at home (often). Also an increased tendency for overwork or increased stress are mentioned as welfare decreasing impacts

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<sup>19</sup> The maximum realistic mitigation potential is defined as the reduction in GHG emissions when teleworking is adopted by the largest number of actors possible, taking into account technical and structural constraints, indirect effects and rebound effects.

of teleworking (CE Delft et al., 2011). Although no empirical evidence is available on the size of all these effects, we expect that the welfare enhancing impacts of teleworking are larger than the welfare decreasing ones. For example, Gareis (2003) shows that in 2002 about 64% of the persons employed in Europe are interested in teleworking, indicating that this behavioural change would enhance the welfare of the majority of the employees.

- *Broad welfare impacts for managers*; managers are often resistant to teleworking, due to a perceived reduction in opportunities to coordinate, motivate and control employees. If employees start teleworking this may therefore reduce managers' welfare.
- *External costs*; the reduction in vehicle kilometres may also result in decreased transport externalities, like air pollutant emissions and noise.

CE Delft (2008a) shows that the sum of the first five cost categories is negative if people start working at home for one day per week. It may be expected that the broad welfare impacts for teleworkers will be positive and will probably be larger than the negative broad welfare impacts for managers. Also the welfare impact of the reduced external effects of transport will be positive. In the end, applying teleworking will result in negative costs from a social perspective. This would also imply that teleworking has a negative cost effectiveness. It is not clear whether teleworking becomes more cost effective if it's applied on a broader scale (more than once a week); on the one hand, the financial cost savings will be larger, but the welfare impacts for managers may become more negative and even the welfare impacts for teleworkers may decline (e.g. people don't want to work at home for more than two days a week).

#### 4.3.4 Applying virtual meetings

The CO<sub>2</sub> impact of business transport could be reduced by applying virtual meetings (more often). This impact will increase if virtual meetings are more often applied instead of face-to-face meetings. CE Delft et al. (2011) estimate that the maximum realistic mitigation potential of applying virtual meetings is ca. 9% of the CO<sub>2</sub> emissions of passenger transport in Europe.

Applying virtual meetings may result in various types of costs and benefits:

- *Lower mobility costs*, since fewer kilometres are travelled for business purposes.
- *Investment costs in ICT*;
- *Increased productivity of employees*; virtual meetings may be more effective than face-to-face ones, increasing employees effectiveness (e.g. by reducing the average time of meetings)
- *Broad welfare impacts for employees*; since employees prefer to meet people in real and business trips are seen as advantages of a job, applying virtual meetings could reduce employees' job satisfaction and hence their welfare (CE Delft et al., 2011).
- *External costs*; the reduction in vehicle kilometres may also result in decreased transport externalities, like air pollutant emissions and noise.

Due to a lack of empirical data, the net costs of applying virtual meetings cannot be estimated. It is also not possible to determine whether the costs will be positive or negative. Therefore, it is not possible to assess the cost effectiveness of this behavioural measure.

## 4.4 Conclusions

In this chapter we analyzed the cost effectiveness of various behavioural measures in the field of transport. Due to a lack of empirical studies on this topic, quantitative cost effectiveness figures could be provided for only one behavioural measure: the appliance of a fuel efficient driving style. According to the literature this behavioural option is very cost effective (-€10 to -€100 per tonne CO<sub>2</sub>), indicated by negative cost effectiveness figures.

However, the analysis showed also the rather large dependence of the cost effectiveness figures on variables like fuel price and investment costs.

With respect to the other behavioural measures, it should be noticed that the cost effectiveness depends both on financial and non-financial cost elements for users and/or vehicle operators as well as changes in infrastructure external costs. Many behavioural options (purchasing a smaller car, a shift from the car to the bike) result in financial cost savings and reduced external costs, but lead also to positive non-financial costs (broad welfare impacts). For some of the options the former cost elements are expected to be larger (e.g. teleworking) and hence cost effectiveness figures are expected to be negative, while for other options (e.g. purchasing small cars) the latter are expected to be larger and hence cost effectiveness figures are expected to be positive. However, there are also options (e.g. purchase of electric cars) for which both cost elements are expected to be positive, resulting in a positive cost effectiveness. Finally, there are options (e.g. applying virtual meetings, modal shift from the car to the bike) for which the sign of the cost effectiveness is not clear.

DRAFT

# 5 Cost effectiveness of policy instruments

## **Objectives:**

The purpose of this sub-task is to explore the cost effectiveness of various GHG policy instruments in the transport sector.

## **Summary of Main Findings**

⇒ Will be added to the final version of the paper

## 5.1 Introduction

In this chapter we discuss the cost effectiveness of various policy instruments that could be used to reduce the CO<sub>2</sub> impact of transport. We focus on instruments for road transport for which empirical evidence on cost effectiveness is available. More specifically, the following policy instruments are considered:

- Fuel taxes
- Road user charges
- Lowering speed limits
- Fiscal measures for commuter and business travel
- Vehicle taxes

Also for fuel standards cost effectiveness figures are available. However, due to the close relationship between fuel standards and technical options to reduce vehicle's fuel use, this policy instrument is discussed in chapter 3.

## 5.2 Fuel standards

A regulative measure that could be applied to reduce the CO<sub>2</sub> emissions of vehicles are fuel standards for new vehicles. In 2009 the European Commission introduces a fuel standard of 130 g CO<sub>2</sub> per km for new passenger cars in 2015. In Regulation No 442/2009/19 a long-term target of 95 g/km is specified for the year 2020. The modalities for reaching this target and the aspects of its implementation are not yet defined and will, among other things, be based on the study performed by Ricardo et al. (ongoing), from which in section 3.2 preliminary results have been used to estimate the cost effectiveness figures of technical options to reduce the CO<sub>2</sub> emission figures of new passenger cars.

No assessments of the cost effectiveness of fuel standards based on the 95 g CO<sub>2</sub>/km target have yet been performed. Therefore, we will present cost effectiveness figures estimated for the 130 g CO<sub>2</sub>/km fuel standards by two studies: European Commission (2007a) and European Commission (2007b). It should be noticed that these cost effectiveness figures are not comparable to the cost effectiveness figures for the technical options presented in section 3.2.

European Commission (2007b) presents cost effectiveness figures for three scenarios on fuel standards:

2. A fuel standard of 120 g CO<sub>2</sub>/km in 2012, which is achieved solely by improvements in passenger cars
- 3A A fuel standard of 130 g CO<sub>2</sub>/km in 2012, which is achieved by improvements in passenger cars + up to 15 g CO<sub>2</sub> reduction by other technical measures, like tyre

pressure monitoring systems and gear shift indicators, technical options for vans and biofuels are taken into account.

- 3B Like variant 3B, but considering in addition a widespread implementation of measures to influence consumer demand (taxation and consumer information).

To estimate cost effectiveness figures these scenarios are compared with a BAU scenario, which assumes CO<sub>2</sub> emission figures for new cars in 2020 of 140 g/km. The costs considered are the costs for the society, equivalent to the sum of consumer surplus, producer surplus, the marginal cost of public funding<sup>20</sup> and external costs. Using the transport model TREMOVE, the Net Present Value of the sum of these costs to society over the period 2010-2020 is calculated, with a discount rate of 4%. The resulting cost effectiveness figures are presented in Table 5.1. Since the cost estimates are based on conservative assumptions (not taking learning effects and economies of scale into account) also an alternative estimate is provided based on 17% lower cost levels.

**Table 5.1: Cost effectiveness figures for various fuel standard scenarios (€/tonne CO<sub>2</sub>) in EC (2007b)**

	Scenario 2	Scenario 3A	Scenario 3B
Cost effectiveness estimate	132	54	24
Alternative cost effectiveness estimate	84	31	6

European Commission (2007a) elaborates on the development of the integrated approach of fuel standards (scenario 3 from European Commission (2007b)). The assessment covers a fuel standard of 130 g CO<sub>2</sub>/km on average for new cars in 2012; another 10 g CO<sub>2</sub>/km reduction should be achieved by other technological improvements and by an increased use of bio-fuels. Three scenarios for the design of this fuel standard have been analysed, varying in how the reduction burden between car manufacturers is shared:

- *Uniform target*: this option sets a common CO<sub>2</sub> emission limit for each manufacturer for the average of their new passenger car fleets sold in 2012. To be workable, this option needs to rely on a trading mechanism providing the necessary flexibility in view of the current diversity of car manufacturers.
- *Utility parameter based limit curve*: a linear function provides the CO<sub>2</sub> limits to be respected as a function of the utility of the vehicle under consideration. Two utility parameters have been identified: mass and footprint.
- *% reduction based targets*: on the basis of the 2006 emission levels averaged per manufacturer, reduction targets are established corresponding to the distance between the current level and the 2012 target.

As in European Commission (2007b), the cost effectiveness figures from a social perspective are estimated by using the TREMOVE model. However, an updated version of this model is used, as a result of which the results from both assessments are not fully comparable. Additionally, the baseline used differs between both studies. Despite these differences between both assessments, the resulting cost effectiveness figures are in the same order (see Table 5.2).

**Table 5.2: Cost effectiveness figures for various fuel standard scenarios (€/tonne CO<sub>2</sub>) in EC (2007a)**

	Uniform target	Utility parameter based limit curve	% reduction based targets.
Cost effectiveness estimate	16	32 - 35	29

<sup>20</sup> This implies that the tax savings for the consumer (from fuel excise duties of the fuel saved) have to be compensated under a hypothesis of constant fiscal revenues for the public sector.

The studies reviewed show that fuel standards of 130 g CO<sub>2</sub>/km are probably rather cost effective. Depending on the design of the fuel standards the cost effectiveness figures range from € 6 to € 54 per tonne CO<sub>2</sub>.

## 5.3 Fuel taxes

By raising the price of fuel, fuel taxes discourage consumption and production of motor fuels. Car users could reduce their fuel consumption by travelling fewer kilometres, drive in a more fuel-efficient way or buy a more fuel-efficient cars. The reduction of fuel consumption and production (and corresponding CO<sub>2</sub> emission reduction) can be calculated by models using price elasticities of fuel consumption.

From a welfare economics perspective, taxes induces negative welfare effects as they reduce the consumer and producer surplus<sup>21</sup>. On the other hand, the income of the government increases. This is a positive welfare effect. The net welfare effects (for the society) of a tax are in general considered to be negative (in economic terms). The reason is the so called 'deadweight loss' or excess burden of a tax, caused by the market distortion a tax induces.

The above reasoning only holds for the economic costs of a tax. Positive external effects have not been taken into account. Fuel taxes may decrease environmental pressure or other external effects, such as CO<sub>2</sub> abatement, lower pollution, less congestion etc. According to Pigou (1938), the founder of welfare economic models including external effects, a tax is optimal when the negative economic effect of the tax equals the positive external effects.

More specifically, the implementation or increase of fuel taxes result in the following costs and benefits (from a societal perspective):

- Reduction in consumer surplus, e.g. reduction in car users' welfare due to a decrease in their travel kilometres.
- Reduction in producer surplus; e.g. less profit for fuel producers.
- Fuel savings
- Co-benefits: lower congestion, noise, pollution and accidents.

In the remainder of this section we discuss various studies assessing the cost effectiveness of fuel taxes from the perspective of the society. Studies presenting cost effectiveness figures of fuel taxes based on a governmental or end-user perspective are not taken into account.

### AGPC (2011)

In AGPC (2011), the cost effectiveness of fuel taxes have been determined for Australia, China, Germany, Japan, New Zealand, South Korea, United Kingdom and USA. Cost and CO<sub>2</sub> abatement have been estimated by comparing observed fuel prices and quantities in each country with a counterfactual scenario in which fuel tax had never been imposed. The economic costs have been defined as the loss in consumer surplus less any transfers to the government through tax revenues. The study does not take a loss in producer surplus into account, by assuming a perfectly elastic supply curve. Positive welfare effects of co-benefits have not been taking into account either. To estimate the impacts of fuel taxes on fuel consumptions, fuel price elasticities ranging from -0.25 and -0.75 are used.

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<sup>21</sup> Consumer surplus is the (monetary) gain obtained by consumers because they are able to purchase a product for a price that is less than the highest price that they would be willing to pay. Producer surplus is the amount that producers benefit by selling at a market price that is higher than the least that they would be willing to sell for.

**Table 5.3: Cost effectiveness figures for fuel taxes in various countries (in €<sub>2010</sub>)**

Country	Abatement costs (€ per tonne)	
	Low	High
Australia	40	41
China	14	16
Germany	79	83
Japan	70	73
New Zealand	50	51
South Korea	58	61
United Kingdom	91	97
United States	13	

Source AGPC (2011)

Values have been converted from Australian Dollars to Euro's. We used the same exchange rate that has been used in this (Australian) study to convert Euro's in Australian dollars (in the case of Germany).

The study shows that the cost effectiveness of fuel taxes range from € 13 per tonne (USA) to € 97 per tonne (United Kingdom, high estimate). The cost effectiveness of fuel taxes are the highest in the EU countries. According to the authors, a reason might be that fuel taxes in Germany and UK were high before the tax raise (see also Table 5.4), suggesting that the marginal cost of reducing emissions becomes higher as more emissions are abated. In other words, the smaller group drivers still driving at higher fuel prices are less sensitive to price changes than the larger group driving at lower fuel prices.

**Table 5.4: Fuel prices considered in AGPC (2011) for the various countries**

Country*	Fuel type	Retail price (€ / l)	Excise duty (€ / l)	Price before duty (€ / l)
Australia	Petrol	0.87	0.27	0.60
	Diesel	0.87	0.27	0.60
	LPG	0.41	0.00	0.41
China	Petrol grade 90	0.67	0.11	0.56
	Petrol grade 93	0.73	0.11	0.62
	Petrol grade 97	0.79	0.11	0.67
	Diesel	0.71	0.09	0.62
Germany	Petrol	1.28	0.65	0.63
	Diesel	1.09	0.47	0.62
	LPG	0.59	0.10	0.49
Japan	Petrol	1.17	0.47	0.70
	Diesel	0.98	0.28	0.70
	LPG	0.69	0.08	0.61
South Korea	Petrol	1.05	0.49	0.56
	Diesel	0.91	0.34	0.58
	LPG	0.54	0.14	0.40
UK	Petrol	1.38	0.68	0.71
	Diesel	1.41	0.68	0.73
	LPG	0.76	0.19	0.56

Source: AGPC (2011)

\* Prices have been converted to € using the same exchange rates as in the Australian study. New Zealand and USA have been excluded from this table, due to the fact that we have not been able to extract this information from the study.

## CE (2010b)

In CE (2010b) the cost effectiveness of a hypothetical fuel tax increase in The Netherlands has been determined (petrol, diesel and LPG). The mobility and CO<sub>2</sub> impacts of this fuel tax increase are estimated by use of the Dutch passenger car model DYNAMO. The (negative)

costs taken into account include consumer surplus reduction and fuel savings (based on factor prices). Co-benefits have been monetized as well, including reduced congestion, reduced pollution, reduced accidents and reduced noise. Using a discount rate of 4%, a petrol price of € 1.35 and a diesel price of € 1.16, a net benefit of €150 per tonne CO<sub>2</sub> reduction (cost level 2008) was found, implying that the fuel savings and co-benefits outweigh the loss in consumer surplus. Taking only the costs of consumer surplus into account, the cost effectiveness determined in CE (2010b) is € 170 per tonne CO<sub>2</sub>. Like AGCP (2011), the reduction of producer surplus has not been taken into account in the study.

### **MNP (2007)**

MNP (2007) has determined the cost effectiveness of a Dutch fuel tax increase (€ 0.1 per litre) from a societal perspective. The impacts of this tax increase on mobility and CO<sub>2</sub> emissions are estimated by using a transport model (FACTS). Costs taken into account are: reduction in consumer surplus, fuel savings (based on factor prices) and co-benefits (congestions, other environmental impacts). Based on this information, a cost effectiveness of -€ 592 per tonne CO<sub>2</sub> (price level 2007) is estimated. However, the authors notice that this cost effectiveness figure depends heavily on the rather unreliable estimates of cost savings due to congestion reduction. Therefore they also provide a cost effectiveness figure for the fuel tax increase without including the congestion benefits. In that case a cost effectiveness figure of € 175 per tonne CO<sub>2</sub> is estimated. Retail fuel prices for petrol and diesel cars were € 1.32 and € 0.96 per litre (it is not clear whether fuel prices excl. or incl. taxes are used to estimate the cost effectiveness figures). No information has been presented on the discount factor used. .

### **Comparison of results**

CE Delft (2010b) and MNP (2007) both estimate negative cost effectiveness figures for fuel tax increases, indicating that the CO<sub>2</sub> abatement costs of this measure is negative. This is in line with ECN (2003), which concludes that increasing the fuel tax is a cost effective instrument to reduce CO<sub>2</sub> emissions. However, the actual value of the cost effectiveness of increasing fuel taxes is rather uncertain. The figures presented by CE Delft (2010b) and MNP (2007) differ significantly: -€150/tCO<sub>2</sub> vs. -€592 per tonne CO<sub>2</sub>. This difference may be the result of, among other things, large differences in the estimated congestion reduction benefits and environmental co-benefits. The latter may be caused by the fact that MNP (2007) uses shadow prices for air pollutants (in € per vkm) from 2002, while CE Delft (2010b) uses figures for 2010. The latter are significantly lower, since air pollutant emissions per vkm have decreased significantly in the period 2003-2010. MNP (2007) probably overestimates therefore the current environmental co-benefits of fuel tax increases.

AGCP (2011) presents positive cost effectiveness figures for fuel taxes, suggesting positive CO<sub>2</sub> abatement costs. However, in contrast to CE Delft (2010b) and MNP (2007) this study does not take co-benefits of increased fuel taxes into account, but only reductions in consumer surplus and fuel savings. If we compare the costs effectiveness figures in terms of reduced consumer surplus and fuel savings for AGCP (2011) and CE Delft (2010b), we find lower cost effectiveness figures for the former study: € 79 to € 97 per tonne CO<sub>2</sub> (based on figures for Germany and UK) vs. €170 per tonne. This difference may be explained by country differences (e.g. average fuel-efficiency of cars) and methodological issues (especially related to the estimation of changes in consumer surplus; the methodology used by AGCP (2011) is not completely clear).

Based on the review of the various studies, we conclude that raising fuel taxes will probably be a very cost effective policy instrument when co-benefits are included, especially in countries having low fuel taxes at the moment. Determining a specific (range of) value(s) of the cost effectiveness that could be applied in the EU is difficult, since the effectiveness and

impacts of fuel taxes depends heavily on national/local circumstances. This is certainly the case with respect to the significant co-benefits (congestion, transport safety, air pollution). More in general, better assessment methods to estimate the impact of fuel tax increases on congestion levels would certainly improve the quality and reliability of cost effectiveness figures of this policy instrument.

## 5.4 Road user charging

Road-user Charging is, in simple terms, a mechanism through which motorists pay to use a defined area of road. There are different forms of road user charging (University of Nottingham 2011):<sup>22</sup> such as area licensing<sup>23</sup>, cordon/zone charging<sup>24</sup>, distance based charging<sup>25</sup>, time based charging<sup>26</sup> and congestion charging<sup>27</sup>. In this paper we focus on national distance based charging schemes.

National road user charging schemes, applying to both passenger and freight transport, may result in significant CO<sub>2</sub> emissions (ECN, 2003). Ex-ante evaluation studies of a national road pricing scheme in the Netherlands show that it may result in a reduction of CO<sub>2</sub> emissions of about 15% (CPB and PBL, 2008). Estimations for a road pricing scheme in the UK show CO<sub>2</sub> reductions equal to 7% (DfT, 2006). However, the CO<sub>2</sub> effectiveness of these kinds of schemes are closely related to their design. Systems that involve differentiation according to CO<sub>2</sub> emissions figures of the car will be more effective than systems applying a flat rate.

National road pricing schemes result in the following costs and benefits:

- *Investment costs of the scheme*; these costs depends heavily on the design of the scheme (only motorways or all roads, only freight transport or all vehicles, flat or differentiated charges, level of desired monitoring, etc.) and the technological system applied (GPS based or a system based on automatic number plate recognition)
- *Operational and maintenance costs*; as for investment costs, these costs depends heavily on the design of the scheme and the technological system applied.
- *Fuel savings*;
- *Welfare loss drivers*, e.g. due to lower mobility;
- *Co-benefits* such as reduced congestion (reduced time losses), pollution, noise and accidents.

In the literature we found two studies presenting cost effectiveness figures for national road charging schemes. First, Anable and Bristow (2007) have carried out a rough calculation for the costs of a national road user charging system in the UK. The set up costs of such a national system, calculated by Deloitte (2004), are in the range from €26 billion to € 71 billion. The annual costs are € 4.6 billion to € 6,2 billion<sup>28</sup>. Anable and Bristow calculate costs of € 2552 to € 3464 per tonne avoided CO<sub>2</sub>, not taking co-benefits of the instrument into account. They use this figures to show that road user charging would be more efficient in targeting congestion than an increase in fuel prices, but that it is not so effective in targeting CO<sub>2</sub> emissions. This does not imply that the measure could still be cost effective from a societal perspective (if also co-benefits are taken into account); only the effect on CO<sub>2</sub> reduction is relatively small.

CE Delft (2010b) presents the cost effectiveness of a Dutch road user charge for passenger cars, taking also co-benefits into account. The investment costs (on a yearly basis) were estimated to be € 267 million a year. The net operational costs (from a Dutch perspective)

<sup>22</sup> [http://www.nottingham.ac.uk/transportissues/cong\\_roadcharging.shtml](http://www.nottingham.ac.uk/transportissues/cong_roadcharging.shtml)

<sup>23</sup> Provision of a license, which enables the user to enter a certain defined area

<sup>24</sup> Involves setting up a linear cordon and charging at access points to the zone

<sup>25</sup> the fee levied is proportional to the distance travelled

<sup>26</sup> implies that a driver is charged a fee related to how much time is spent on charging roads, or in an urban area, within a cordon

<sup>27</sup> the fee levied is related to the amount of congestion caused by a car's journey

<sup>28</sup> We used the following exchange rate 1£ = 1,15 €. <http://www.xe.com>. 10-10-2011

are assumed to be negative, mainly because the co-benefits (i.e. reduction in travel time losses) outweigh the operational and investment costs of the charging system. Negative abatement costs ranging (depending on the design of the scheme) from -€38 to -€99 per tonne CO<sub>2</sub> are estimated.

Based on the results presented above we conclude that road charging systems could be a cost effective instrument to reduce transport CO<sub>2</sub> emissions. This follows from CE Delft (2010b), which shows that the proposed road pricing scheme for the Netherlands result in negative CO<sub>2</sub> abatement costs. Anable and Bristow (2007) suggest that road charging is a rather cost ineffective CO<sub>2</sub> abatement measure, but they do not take the main benefit of these schemes (reduced congestion) into account. Based on their analysis it could be concluded, however, that road charging schemes are more appropriate if congestion reduction is the main target. If CO<sub>2</sub> reduction is the main target, fuel taxes are probably a more effective measure. Finally, it is important to mention that the (cost) effectiveness of this instrument depends heavily on its features and design, e.g. whether it is used on a national scale or solely in selected areas, whether it is applied to motorways or regional roads, whether it covers all vehicles or only selected segments, technical features, the tariff structure etc. Also country specific characteristics, e.g. the extent of congested roads, affect the cost effectiveness of road charging schemes. For these reasons it is impossible to point to generic conclusions with respect to the cost effectiveness of road pricing.

## 5.5 Lowering speed limits

As was mentioned in the previous study on *EU Transport GHG: Routes to 2050?* lowering speed limits for road transport could be an effective measure to reduce CO<sub>2</sub> emissions.

However, this measure also provides a broad range of (negative) costs:

- Travel time losses;
- Fuel savings;
- Co-benefits on air pollution, noise, accidents, congestion and infrastructure investments and maintenance;
- Potential long term impacts on spatial structures;
- Costs and revenues of enforcement.

In a study of Rietveld et al. (1996), it was concluded that from the point of view of total welfare (including impacts on travel time losses, fuel savings, climate change, air pollution, and traffic safety), the most beneficial maximum speed limit on the motorway lies somewhere around 90 km/h. Based on a Swedish study, ECN (2003) concludes that the optimal maximum speed on motorways would be between 90 and 100 km/h. More recently, Transport and Mobility Leuven (TML) issued a report on the impacts of speed limit on motorways (TML, 2009). Based on the impacts on travel times, air pollutant emissions, CO<sub>2</sub> emissions and traffic safety, this study concludes that the most beneficial maximum speed limit is one of 110 km/h. Unfortunately, these studies do not provide specific cost effectiveness figures. However, since the optimal speed limits presented in these studies are lower than the actual speed limits implemented in the countries to which their assessments refer, it could be concluded that according to their assessments lowering of the speed limits is a cost effective measure.

A study presenting specific cost effectiveness figures for lower speed limits is CE Delft (2010b). In this study two scenarios are assessed: 1) a reduction of existing motorway speed limits of 120 km/h to 100 km/h, and 2) a reduction of existing motorway speed limits of 120 and 100 km/h to respectively 100 and 80 km/h. Costs included by this study are: travel time losses, welfare impacts of the reduction in total mobility, reduced infrastructure costs, improved road safety and positive environmental impacts. Based on these costs, the cost effectiveness of the first speed limit scenario is estimated at ca. € 250 and € 420 per tonne

CO<sub>2</sub>. The main part of these positive CO<sub>2</sub> abatement costs is due to the costs of travel time losses.

Based on the results presented above, it is difficult to present some general conclusions on the cost effectiveness of lowering speed limits. Since the effects and costs of lowering speed limits depends heavily on local characteristics (initial speed limits, intensity/capacity ratio of roads, initial congestion levels, etc), it is hard to transfer results from the specific case studies to European values. Also the design of the measure (the number of km/h by which the speed limits are lowered, the level of enforcement applied) affects the cost effectiveness of the measure, as is shown by the results of the various scenarios in CE Delft (2010b).

## 5.6 Fiscal measures for commuter and business travel

Fiscal measures to reduce the amount of commuter and/or business travel could be an effective way of reducing mobility related CO<sub>2</sub> emissions (see Van Essen et al., 2010). The number of studies providing cost effectiveness figures for these kinds of instruments is limited. Only CE Delft (2010b) provides a cost effectiveness figure for a reduction of the tax-free compensation for commuter and business travel in the Netherlands.

Currently, employers can provide a tax-free compensation of € 0.19 per kilometre to employees to compensate their commuter and business travel costs. For about 50% of the commuter and 100% of the business kilometres such a tax-free compensation is provided by employers. CE Delft (2008b) has estimated the cost effectiveness if this compensation for car users is reduced to € 0.12 per kilometre, taking the following costs and benefits into account:

- Reduction of travelling costs by car;
- Costs of public travel, for those commuters who choose to travel by public transport instead of by car;
- Reduction of consumer surplus, e.g. welfare loss of people starting to work at home more often, but who prefer to work at the office.
- Co-benefits: lower congestion, noise, pollution and accidents.

Based on a discount rate of 4%, CE Delft (2010) estimates cost effectiveness figures ranging from € - 338 per tonne to € - 84 per tonne (price level 2008), suggesting that benefits outweigh the lower consumer surplus and increase of public travel costs.

Empirical evidence on the cost effectiveness of fiscal instruments for company cars is to our knowledge not available. Providing general conclusions on the cost effectiveness of these schemes is impossible, because these schemes differ widely throughout Europe (Copenhagen Economics, 2010). However, increasing company car taxation will probably be effective in reducing CO<sub>2</sub> emissions of passenger road transport (Puigarnau and Van Ommeren, 2007), while the same have been proved with regard to CO<sub>2</sub> differentiation of company car taxes in the UK and the Netherlands (CE Delft, 2008; HM Revenue & Customs, 2006; Ecorys, 2011). These measures may result in various costs and benefits, including a reduction in consumer surplus (welfare loss of employees who choose not to have a company car anymore, decrease in kilometres since the end-user costs of private travelling increase), additional investment and/or operational costs for the private car, fuel savings, and co-benefits (less air pollution, increased traffic safety, less congestion, etc.). Since the size of some of these costs/benefits is difficult to predict, it is not possible to provide qualitative estimations on the net CO<sub>2</sub> abatement costs of these policy instruments.

## 5.7 Vehicle taxes

The ownership of vehicles could be affected by vehicle taxes. Two main types of vehicle taxes exist: purchase or registration taxes and annual circulation taxes. In most of the European countries these taxes are implemented, often with some kind of CO<sub>2</sub> element (Van Essen et al., 2010). An increase of vehicle tax levels (particularly in case of purchase taxes) may result in lower CO<sub>2</sub> emissions, although little empirical evidence is available. Another strategy is to differentiate the vehicle tax to CO<sub>2</sub>. Particularly in case of purchase taxes this may be an effective option; CE Delft et al. (2011) estimates CO<sub>2</sub> emission reductions of up to 10% if a CO<sub>2</sub> differentiated purchase tax is implemented.

An increase or CO<sub>2</sub> differentiation of vehicle taxes may result in various costs and benefits. At least the following issues should be taken into account: change in consumer surplus (e.g. consumers owning fewer cars or smaller cars), possible changes in producer surplus, fuel savings, changes in government income, and co-benefits (less air pollution, increased traffic safety, etc.).

The cost effectiveness of changes in vehicle taxes are scarcely researched (Anable and Bristow, 2007). Naturvårdsverket (2002) investigates the costs and benefits of a CO<sub>2</sub> differentiated registration and circulation taxes. They conclude that both instruments are rather costly with respect to reducing CO<sub>2</sub> emissions. However, from a methodological point of view this study is rather poor (e.g. not all costs and benefits are taken into account) and hence these results are not reliable. Another study assessing the cost effectiveness of vehicle taxes is MNP (2007), which has calculated the cost effectiveness of a tax exemption for the Toyota Prius in The Netherlands. The analysis shows that the abatement costs decrease when the relative amount of the tax exemption decreases. For a full tax exemption (€ 8,000), the calculated value was € 600 per tonne CO<sub>2</sub>. When the tax exemption is 50% (€ 4,000) the abatement costs drop to € 100 per tonne. If the tax exemption is lower than 40%, the abatement costs become negative implying a positive welfare effect. According to the authors the reasoning is that the government income increases faster than the decrease in consumer surplus when the tax exemption decreases.

## 5.8 Conclusions

Both the impacts (in terms of reduction of CO<sub>2</sub> emissions) and (negative) costs of policy instruments depend heavily on the design of the instrument (e.g. tax structure, scope of the scheme, level of enforcement, etc.). Additionally, impacts and costs are affected by local/national characteristics; for example, a fuel tax will probably more effective if countries possess a high quality public transport infrastructure network. For these reasons it is not possible to provide general conclusions on the cost effectiveness of the various policy measures. The results presented in this chapter should therefore be considered as illustrative cases and hence could not be transferred to other cases. Due to same reasons a direct comparison of the cost effectiveness of various policy instruments is complicated.

The analysis carried out in this chapter provide empirical evidence that fuel standards, fuel taxes, road user charges and some of the fiscal measures for commuter and business travel could be cost effective, depending on its design and local context. Due to a lack of information no conclusions could be presented for the other policy instruments.

# 6 Conclusions

## 6.1 Introduction

In this final chapter we summarise and compare the main results presented in the previous three chapters on cost effectiveness. We distinguish between cost effectiveness figures of GHG reduction measures (both technical and behavioural ones) and policy instruments. As outlined in chapter 2, the value of cost effectiveness figures depends on a wide range of assumptions and hence the comparison of different measures/instrument should be done carefully.

## 6.2 Technical and behavioural options

The assessment of cost effectiveness of technical and behavioural options, as presented in chapter 3 and 4, provides quantitative figures for the following options: technical abatement options for passenger cars and heavy duty vehicles, and fuel efficient driving. For the other technical and behavioural options the available evidence was too limited (of completely missing) for determining quantitative cost effectiveness figures. For these options we applied a qualitative assessment.

Based on the quantitative and qualitative assessments we can conclude the following:

- For passenger cars, various technical options with negative abatement costs are available for the period until 2020. The abatement costs for diesel cars are mostly lower than for petrol cars, which is due to lower add-on costs for many of the technical options on diesel cars. The various technical options could be combined to lower the emissions of a small/medium petrol or diesel car from 130 g/km to 95 g/km, resulting in cost effectiveness figures of ca. € 38 for a petrol car and -€ 12 for a diesel car. As shown in section 3.2 these cost effectiveness figures depends heavily on the fuel price and discount rate assumed.
- Also for heavy duty vehicles various technical options with negative abatement costs are available for the period until 2020. By stacking various reduction measures (in an efficient way) for a medium duty heavy vehicle (ca. 12 tonne) at least 16% CO<sub>2</sub> emission reduction could be realised with negative abatement cost (-€ 28 per tonne CO<sub>2</sub>). For heavy duty heavy vehicles (ca. 40 tonne) at least 30% CO<sub>2</sub> emission reduction could be realised with negative abatement costs (- € 63 per tonne CO<sub>2</sub>).
- Based on the literature review, cost effectiveness figures ranging from -10 to -100 per tonne CO<sub>2</sub> are found for the appliance of a fuel efficient driving style. The rather wide range in the cost effectiveness figures is mainly explained by variances in fuel prices assumed. These cost effectiveness figures are not directly comparable to the ones presented for the technical reduction options for passenger cars and heavy duty vehicles, due to differences in fuel prices (in the assessment on cost effectiveness figures for technical options for passenger cars and trucks higher fuel prices are assumed than in the assessments considering fuel-efficient driving) and BAU scenario (in the assessments considering technical reduction options for passenger cars and trucks CO<sub>2</sub> emission figures for an average vehicle from 2015 was used, while in the assessments considering fuel-efficient driving an average car from 2008 was assumed).
- Recent studies on the abatement potential of biofuels show that due to indirect land use change (ILUC) effects many biofuels will result in a net increase of GHG emissions. Therefore, it is not possible (and useful) to determine cost effectiveness figures for biofuels.
- Based on a qualitative assessment we expect that the purchase of an electric/plug-in hybrid car will (in the near future) not be cost effective, particularly since both investment

costs and broad welfare costs (since most people prefer a conventional car over an electric one) will be rather high.

- For the purchase of smaller cars we expect positive cost effectiveness figures. The lower investment, operational and external costs are probably undone by rather high welfare costs, since people have a strong preference for large cars. Based on the qualitative assessment carried out we are not able to estimate the size of the cost effectiveness figure.
- Based on a qualitative assessment we expect negative abatement costs for teleworking, at least if it is applied on a small scale. Applying teleworking on a larger scale (more than once a week) may affect the cost effectiveness of teleworking in two ways: on the one hand financial savings for firms may become larger (they can reduce the size of their offices), but on the other hand the welfare costs for managers (fewer opportunities to monitor employees) and teleworkers (social isolation) may increase.
- For the behavioural options 'modal shift' and 'applying virtual meetings' it was not possible to determine the sign or size of their cost effectiveness.

### 6.3 Policy instruments

The empirical evidence on cost effectiveness figures for policy instruments is rather limited. Based on the evidence that is available we can conclude the following:

- For at least some of the policy instrument assessed in this study (fuel standards, fuel taxes, road charges, and some of the fiscal measures for commuter and business travel) it is possible to implement them in a cost effective way. For lowering speed limits and vehicle taxes the evidence on its cost effectiveness is not clear or too limited
- Whether or not a policy instrument will be cost effective depends heavily on its design (e.g. tax structure, scope of the scheme, enforcement level) and the national/local context. The impact of the design of the instrument on its cost effectiveness is clearly shown by the studies concerning fuel standards. For example, European Commission (2007b) presents cost effectiveness figures ranging from € 24 to € 134 per tonne CO<sub>2</sub> for three variants of fuel standards. An example of the dependency of cost effectiveness figures on the national context is shown by AGPC (2011), which shows that a fuel tax is more cost effective in European countries (i.e. UK and Germany) than in, for example, the US. According to the authors this could probably be explained by the fact that the initial fuel prices in the European countries were higher than in the US, suggesting that the marginal cost of reducing emissions becomes higher as more emissions are abated.
- An important factor in the cost effectiveness calculations of policy instruments directly affecting transport demand (e.g. fuel taxes, road user charges) is the way (the reduced) congestion costs are estimated. The various studies taking this cost into account show that it contributes heavily to the net costs of the instrument assessed. However, the approach to estimate the value of this cost is often rather rough. Therefore, these results should be considered carefully.

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