EC - DG ENTERPRISE AND INDUSTRY

COST-EFFECTIVENESS OF GREENHOUSE GASES EMISSION REDUCTIONS IN VARIOUS SECTORS

FINAL REPORT

Framework Service Contract No Entr/05/18
Zurich/Bern, 30 November 2006

INFRAS (Mario Keller, Samuel Mauch, Rolf Iten, Sonja Gehrig)
IFEU Heidelberg (Udo Lambrecht, Hinrich Helms, Horst Fehrenbach, Andreas Patyk)
IVL Stockholm (Jenny Gode, Erik Särnholm)
TNO Delft (Richard Smokers)
TU Graz (Stefan Hausberger)

GHG_FINAL-REPORT-E_.DOC

INFRAS

MÜHLEMATTSTRASSE 45
CH-3007 BERN

t +41 31 370 19 19
f +41 31 370 19 10
BERN@INFRAS.CH

GERECHTIGKEITSGASSE 20
CH-8039 ZÜRICH

WWW.INFRAS.CH

OVERVIEW

TABLE OF CONTENT

EXECUTIVE SUMMARY

Objective

The first (and main) objective is to compare the costs of greenhouse gases emission reductions (expressed in €/t CO_2-equivalent) in different sectors in the timeframe 2008-2012. The target against which the cost-effectiveness of possible greenhouse gases emission reductions in different sectors has to be compared is the EU Kyoto target for the first commitment period 2008/2012 of an 8% reduction compared to the base year (1990). A special focus was to be put on the analysis of the transport sector.

A second objective is to presemt the theoretical approaches of how emissions trading could be applied to the road transport sector and assess what some of the effects of emissions trading might be.

Emission development perspectives (scenarios)

Various scenarios for the GHG emission development between the base year (1990) and 2008/2012 were defined:

- A baseline scenario S0, including autonomous trends plus the effects of measures already in place.
- A scenario S1 where the effects of planned measures are superimposed on S0.

Table T-1 shows the key data for the base year (1990), scenario S0 and scenario S1:

Mtonnes CO_{2eq}	Base year (1990)	Scenario S0 (2010)	Scenario S1 (2010)	Kyoto target (average 2008-2012)	Gap from Scenario 1 – Kyoto target
EU15	4075	4051	3909	3749	160
EU10	1027	813	813	959	-146
EU25	5102	4864	4722	4708	14

Table T-1 Emission levels for EU15, EU10 and EU25

Additional Emission reduction Policies and Measures: Potentials and Costs

As can be seen from Table T-1 a gap remains in scenario 1 to the Kyoto target (small for EU25, but significant for EU15). The main effort of the project was to identify additional policies and measures over and above those of scenario S1, to further reduce emissions by 2008-2012, estimate their individual reduction potentials (Mtonnes/a) and associated Marginal Abatement Costs (MACs, in €/t CO_2-equiv.). The key results aggregated over all sectors are shown in Figure F-1.

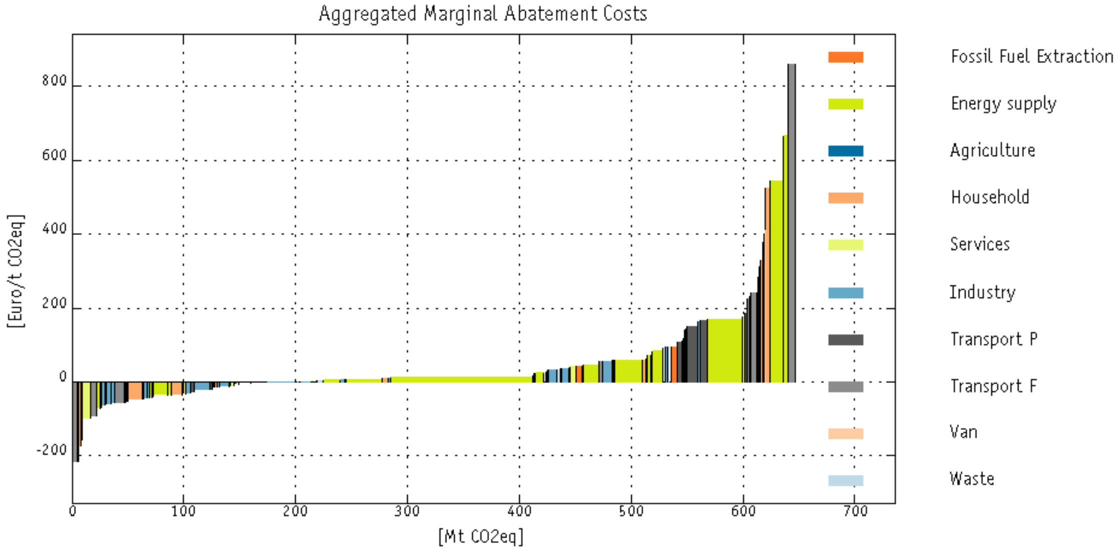


Figure F-1 EU25: Aggregate MAC curve for all measures available for further reduction beyond scenario 1. The various colours represent different sectors, as shown to the right in the figure.

From the analysis and this figure one can conclude:

› In total, there is a large number (around 200) of individual (additional) measures from all sectors, contributing smaller and larger emission reductions at net costs (MACs) between minus 200 €/t and more than +800 €/t. The total of reductions amounts to some 650 Mtonnes/a.

› Different sectors contribute differently to the total reduction:

Out of this total of 650 Mtonnes/a the energy supply sector accounts for almost 50% of the total reduction potential, and also industry shows a considerable share (22%). The road transport could contribute about 13% (or 83 Mtonnes/a), as much as the remaining sectors together (household, services, waste). The contributions of the agricultural and forestry sectors are negligible.

› Out of the 650 Mtonnes/a about 200 Mtonnes/a can be reduced at net costs below 0 €/t CO_2-eq., and a total of 400 Mtonnes/a with measures at costs not higher than about 20 €/t (EU25).

› For EU25 the latter case (400 Mtonnes/a reduction beyond scenario S1) implies a reduction of 15.6% against 1990, which surpasses the Kyoto target for EU25 by more than 8 % (15.6%-7.4% = 8.2%).

Fulfilling the Kyoto targets

While the estimated (according to our assumptions: most probable) gap to the Kyoto target for EU25 is only 14 Mtonnes/a, the situation looks quite different for EU15. To meet its target of -8% for EU 15, a gap of 160 Mtonnes/a must be closed with additional measures (beyond measures in place and planned). Yet, according to the figure above, this is possible with measures with mostly negative, or only small costs (<20€/t, the largest contribution stemming from Natural Gas Combined Cycle [NGCC]). This statement holds even if some of the behavioural measures involved may have implementation degrees lower than assumed in the analysis of this report.

Our calculations seem to be robust relative to a possible underestimation of the gap of 14 Mtonnes: Even if, for EU 25, the gap would not be 14, but in the order of 200 Mtonnes, the additional measures needed to close that gap could be implemtented at marginal costs (MAC) not higher than about 20 €/ton, according to the figure above.

The role of the 120g/km-strategy in the Passenger Car sector

In support of the Impact Assessment, to be performed by the European Commission in preparation of a new strategy aimed at reducing the CO_2 emissions of light-duty vehicles to a level of 120 g/km in 2012, two studies (Task A resp. Task B) have been carried out. This study is based on the results from Task A (TNO 2006) which concludes that the measures to reach the 120 g/km goal show costs significantly higher than the costs for the measures required to reach the Kyoto target under the assumption of a cost effective “path to Kyoto” as shown in the aggregated MAC curve (figure F-1). Task B (reported in ZEW 2006) shows that the additional costs for going from 140 g/km to 120 g/km lead to negligible or at most modest impacts on transport behaviour, vehicle purchase behaviour and various macro-economic indicators. However, Task B arrives at different values for the CO_2-abatement costs, which are lower for most options studied, but higher for some options. Nevertheless it can be concluded that using the results of Task B in this study instead of Task A would not have led to significantly different conclusions as for most options the abatement costs as assessed in Task B also remain above the 20 €/tonne threshold which is found to be typical for options playing a role in reaching the Kyoto target.

It also has to be noted that the reduction potential of measures to achieve 120 g/ km for passenger cars is rather limited in the considered timeframe (2008 to 2012), but can be expected to increase after 2012.

In short

Overall the results of the MAC analysis show that:

› A large number of measures are available at negative or near zero cost, which – taken together can fulfil the Kyoto obligations easily for EU25, and at reasonable cost (<25€/t CO_2-eq.) even for EU15, provided a cost effective path is implemented such as shown in the aggregate MAC curve of chapter 8.2 This requires that different sectors can (or must) participate with different degrees of reduction (in % of their baseline emissions 2010).

- The analysis of the reduction potentials, including the related degrees of implementation suggests strongly that much emphasis be given to the problem of overcoming implementation hurdles and resistances. Specifically this applies to many of the behavioural measures. Examples in the transport sector are Eco driving or freight logistics.
- Specifying the same % of reduction obligation for each sector would be far off from such an optimal path. For example, the optimal path includes much less reduction (in %) from the road transport sector than, e.g. the energy supply or industry sector. The reason is that the latter sectors have more potentials for low cost reduction available, even in % of their significant volumes of baseline emissions. The transport sector, on the other hand, has a much higher gap (in percent of 1990 emissions) to close between its baseline emissions in 2010 and the Kyoto targets. Additionally its potentials for low cost reduction are more limited.
- These are the reasons why it does make economic sense to extend the present EU-ETS system to road transport (and possibly even to other sectors as well). If the system can be designed such that transaction costs are low, this will create market forces which do seek the optimal pathway. Trading as instrument to implement measures may be directed toward overall economic efficiency across all sectors or towards economic efficiency of regulations aiming at reducing emissions within the transport sector.

Extension of the EU ETS to include the road transport sector

Approaches for an extension of the EU ETS

This study presents a broad overview of different approaches to include road transport in the EU emission trading system. As such, the study identifies the following options:

- **Downstream trading** makes the **operators of transport vehicles** liable to hold certificates for the emissions of their vehicles. The **main advantage** is that downstream trading principally allows for a wide range of reduction options on the side of the liable actors (choice of vehicles and fuels, loading and logistics, driving behaviour, etc.). For the entire transport sector, however, the downstream approach would have the **disadvantage** of a very high number of actors and thus high transaction costs. The downstream approach is thus not suitable for the entire transport sector, but has advantages for certain sub-sectors. As a potential area of application, the freight forwarders have been identified.
- The **passenger car manufacturer** approach (also called midstream approach) has several advantages depending on whether a "closed" or an "open" approach is used.

Under a "closed system" it generates effective incentives to the manufacturers to implement the many technical options to directly reduce the specific emissions of their vehicles. Furthermore, transaction costs will be lower as in the other approaches due to the limited number of actors and the already existing EU monitoring of specific emissions of passenger cars. However, the individual use of vehicles (vehicle miles travelled, driving behaviour), can not be influenced directly by car manufacturers. The closed approach, however, is not a "classical" ETS where tonnes of emissions of CO_2 are traded. Rather, it focuses on specific rather than absolute emissions, i.e. on g/km rather than tonnes. Some disadvantages and risks should be considered though: it has to be ensured that trading is actually taking place which might require complex governmental control to give the actors planning reliability including sanctions for the case of non-compliance; the system is economically less efficient than a system open to all sectors since intersectoral trading is not feasible (or would be complex to install); hence the achievement of absolute emission reductions can not be ensured.

A more detailed hypothetical analysis of the effects of the "open system" is presented separately. The main advantage of such is a system is that it would be economically much more efficient than a closed system or a specific target based approach and would impose significantly lesser cost burdens on the automotive industry. The outstanding issues include the need to develop a mechanism by which such an approach could be integrated into the current EU ETS as well as the development of means which would ensure that car manufacturers would continue improving the fuel efficiency of their vehicles through technological improvements.

- With the **upstream approach** (fuel suppliers) all transport related emissions can be included in emissions trading with a limited number of participants and thus transaction costs. Furthermore, the upstream approach allows for an absolute emission cap and can thus also lead to guaranteeing absolute emission reductions. Given the wide coverage of this approach there would be an incentive for the realisation of the most cost effective measures since it covers the whole range of technical and behavioural measures for all road transport vehicles. On the other hand there are some disadvantages of the upstream approach. The liable actors (fuel suppliers) do not have many possibilities for direct emission reductions. The main effect will be an increase in fuel prices which may give an incentive for emission reductions on the side of the end consumer. In an open emissions trading and with current certificate prices, transport could act as buyer since reduction costs are higher as in other sectors. With current certificate prices it can be assumed that open emissions trading is not suitable to stimulate the implementation of technical measures at vehicles or major behavioural changes.

Next analytical steps toward an Extension of ETS to the road transport sector

In this report a first overview of options for ETS extension is presented. A number of issues do call for more detailed examination, however. The following steps are proposed for such an investigation procedure.

- The approaches favoured by the Commission on the basis of present results should be explored in more details. This requires a discussion of the political feasibility including strategic objectives (like “trading emissions” vs. “trading standards”). This would include a workshop with stakeholders, because this would lead to a broader picture of the advantages and disadvantages as articulated by stakeholders, which is considered important from the point of view of acceptance and chances for realisation.
- Assess the effects in view of the period after 2012. Since it is rather unlikely that the time is sufficient to implement an ETS extension to be effective during the next trading period (2008-2012), it is important to look ahead toward the following period (e.g. 2013-2020). This will involve an extension of the emission perspectives and of the impacts over the next decade or so.
- Transitional issues: Given that the inclusion of the transport sector in a “classical” emission trading scheme until 2012 is unlikely it seems important to study solutions which might support a frictionless transition toward an emissions trading scheme later on.
- In particular the car manufacturer approach could be considered to help to achieve the EU targets for specific emissions of cars (g CO_2/km). Some possible effects of applying this approach have been discussed in this report, but have to be analysed in more detail.

1. CONTEXT AND OBJECTIVE OF THE STUDY

1.1. CONTEXT

The European Union is making considerable effort to tackle climate change. Under the Kyoto protocol, the EU has committed itself to reducing its greenhouse gas emissions by 8% compared to the base year (1990) during the first commitment period 2008/2012. A comprehensive package of policy and legislative measures has already been put in place to reach this target. Each Member State has also put in place a series of domestic actions. Domestic policies and measures in EU15 Member States that are projected to contribute most to achieving the targets include the EU emission trading scheme, promotion of electricity from renewable energy, promotion of combined heat and power (CHP), improvements in energy performance of buildings and energy efficiency in large industrial installations, promotion of the use of energy-efficient appliances, promotion of biofuels in transport, reducing the average carbon dioxide emissions of new passenger cars, recovery of gases from landfills and reduction of fluorinated gases.

Despite the EU's considerable effort, latest projections for 2010 (EEA 2005a) show that existing domestic policies and measures by Member States to reduce emissions are not sufficient for the EU15 to reach its Kyoto target. Existing domestic policies and measures will reduce total EU15 greenhouse gas emissions by only 1.6% from base-year levels by 2010. When the additional domestic policies and measures being planned by Member States are taken into account, an EU15 emissions reduction of 6.8% is projected. However, this relies on several Member States cutting emissions by more than is required to meet their national targets, which cannot be taken for granted.

From 1990 to 2003 EU15 greenhouse gas emissions decreased from most sectors (energy supply, industry, agriculture and waste management). However, emissions from transport increased by nearly 24% during the same period. Transport caused the largest increase in greenhouse gas emissions between 1990 and 2003 (+ 24%). Road transport was by far the biggest transport emission source (94% share). Emissions increased continuously due to high growth in both passenger and freight transport by road (by about 30% and 50%, respectively between 1990 and 2003). For 2010, the current EU15 emissions increase is projected to continue up to 31% above 1990 levels with existing domestic policies and measures. Carbon dioxide emissions from international aviation and navigation are growing faster than emissions from other transport modes. They share a combined increase of 49% from 1990 to 2003.

The European Council at its March 2004 meeting asked for "a cost benefit analysis which takes account both of environmental and competitiveness considerations", as preparation for a discussion on “medium and longer term emission reduction strategies, including targets”. The Commission in its Communication “Winning the battle against climate change”(EC 2005) made it clear that it is “imperative to use the most efficient and least-cost mix of adaptation and mitigation actions over time to meet the EU environmental objectives while maintaining our economic competitiveness”.

1.2. OBJECTIVES

The objective of this study is to provide the Commission with an **overview of the cost-effectiveness of greenhouse gases emission reductions in the various sectors**. The main objective is to compare the costs of greenhouse gases emission reductions (expressed in €/t CO_2 equivalent) in different sectors in the timeframe 2008-2012. The target against which the cost-effectiveness of possible greenhouse gases emission reductions in different sectors have to be compared is the EU Kyoto target for the first commitment period 2008/2012 of an 8% reduction compared to the base year (1990). Based on this overview, an indication should be given of the most cost-effective distribution of emission reductions between different sectors to meet the Kyoto target.

In addition, a special focus should be made on the cost-effectiveness of possible greenhouse gases emission reductions in the **road transport sector**. While assessing the cost-effectiveness of further reductions of CO_2 emissions from passenger cars, the available information on the costs to reach the Community target of 120 g/km CO_2 emissions by 2012 should be taken into account. Finally it should be assessed whether the most cost-effective greenhouse gases reduction could be achieved by an extension of the **EU Emission Trading Scheme** to other sectors, in particular the road transport sector. Implications of the different policies and measures on longer term greenhouse gases emission reductions i.e beyond the year 2012, should be indicated.

1.3. STRUCTURE OF THIS REPORT

In order to respond to the questions mentioned above the following tasks have been identified which are also reflected in the structure of the report:

Chapter 2 describes the methodological framework for the study. Apart from providing common definitions (e.g. definition of scenarios, of sectors, of system boundaries, timeframes, geographical scales etc.) such a framework is necessary in particular because it was not the intention of this study to produce new estimates of emission reduction potentials or costs. The study was rather focusing on the comparison of results of existing studies and reports.

Chapter 3 gives an overview about reports and studies which have been used for the comparison of the cost effectiveness of greenhouse gases emission reductions in the various sectors.

In **Chapter 4** the results, i.e. emission reduction potentials and costs of the measures and policies in the various non-road sectors are presented. These results are based on data found in the literature and have been adapted to the common basis for this study.

Chapter 5 presents the analogous results (costs and emission reduction potentials) for the road transport sector. Here a more detailed cost-effectiveness analysis is added, giving more detailed attention over and above the analysis of the other (non-transport, non-road) sectors.

In **Chapter 6** the scenarios underlying the study are presented. Using actual information, a new updated baseline is presented (defined as autonomous trend plus measures and policies in place) and a scenario including “planned measures”.

Chapter 7 discusses “pathways to Kyoto”. Based on a comparison of the cost-effectiveness within and between sectors indications of the most cost-effective distribution of emission reductions between different sectors to meet the Kyoto target is given. In addition, a sensitivity analysis is presented and long term implications are addressed.

Chapter 8 gives an overview about the Emission Trading Scheme as one option to achieve the targets of the Kyoto protocol. Several possible designs and potential regulation accesses which allow for an inclusion of the transport sector in European emissions trading are described and discussed.

2. METHODOLOGY

2.1. INTRODUCTION

This chapter defines a uniform framework and methodology, common for all partners working on different parts of the project. The methodology addresses primarily the following topics:

- Framework conditions, assumptions and definitions of scenarios
- Quantification (scenario development)
- Methodology for extracting MAC (marginal abatement costs) data per sector
- Emission Trading: extending the EU ETS to the road transport sector

This chapter covers the general methodological aspects, applicable to all sectors. Sector specific details are treated in the chapters 3, 4 and 7 respectively.

2.2. FRAMEWORK CONDITIONS, ASSUMPTIONS AND SCENARIO DEFINITIONS

Sectors

The project uses the following structure of sectors:

No.	Name of sector	
1	Energy Supply	
2	Fossil Fuel Extraction	
3	Industry (Manufacturing)	
4	Households	
5	Services	
6	Agriculture and Forestry	
7	Waste	
8	Transport	
	8a	Heavy Duty Vehicles (HDV)
	8b	Passenger Cars (PC)
	8c	Non-Road Transport

The rules for the allocation of GHG Emissions to the energy supply sector and to the various demand sectors are in accordance with Blok 2001a/b:

"The emissions reported in the bottom-up analysis for each sector comprises of direct and indirect emissions. Indirect emissions originate from electricity and steam production and refineries (the so-called energy supply sector). The (direct) emissions of the energy supply sector are allocated as indirect emissions to the energy demand sectors based on their use of electricity

and heat. The energy demand sectors with the main indirect emissions are industry, households and commercial and public services.

Indirect emissions (emissions from energy supply sector) can be reduced by using less energy (i.e. improving the production processes in the energy demand sectors) or by improving the energy conversion efficiencies in the energy supply sector, i.e. using less fossil fuel to produce the same amount of electricity, steam and (converted) fuel. In this report, emission reduction that is obtained by improving the production process of energy demand sectors is allocated to the energy demand sector, regardless whether the option reduces the direct and/or the indirect emissions of the sector. The total reduction potential can therefore only be expressed as a fraction of the total emissions.

This approach differs from the approach followed by PRIMES which allocates the total emission reduction from both improved use and improved generation of electricity and steam to the energy supply sector, regardless the activity takes place on the industrial site or not."

This holds for the quantification of the baseline and the other scenarios, as well as for allocation of the GHG reduction effects of measures, i.e. energy (the associated CO_2 emissions reductions, respectively) are allocated to the energy supply sector if the energy produced can potentially be distributed / sold to third parties, otherwise to the demand sectors (like industry, household etc).

GHG Components

All six GHG components according to the Kyoto protocol are considered- as far as data is available in the literature:

Component	Global Warming Potential
carbon dioxide (CO_2)	1
methane (CH_4)	21
nitrous oxide (N_2O)	310
hydrofluorocarbons (HFCs)	f(HFC): 140 … 11'700
perfluorocarbons (PFCs)	f(PFC): 6'500 … 9'200
sulfur hexafluoride (SF_6)	23'900

Table 1 Greenhouse Gas components considered.

Quantitative GHG data is always given in CO_2 equivalents, i.e. tons or Mtonnes of CO_{2eq}.

Scenarios

For the project's analysis work, the following scenarios are defined

- **Scenario S0** (= baseline scenario) includes the trend development plus those measures and policies already in place (in 2006). A gap of G0 toward meeting the Kyoto target remains.
- **Scenario S1** includes, over and above scenario S0, the measures planned in the EU. A gap of G1 remains toward fulfilling the Kyoto target.
- An additional **Scenario S2** is defined in which the Kyoto target of -8% for EU 25 should be achieved. However, this scenario is not elaborated in detail, it rather serves as quantitative benchbark and as background for a qualitative discussion of additional (alternative) measures to fill the gap G1. This discussion includes – apart from the general list of measures in all sectors – in particular the introduction of the Community target of 120 g/km CO_2 emissions by 2012 for passenger cars and the effects of extending the EU ETS to the road transport sector.

For the transport sector, Scenario S1 is defined (assumed) to be the same as scenario S0 because no specific measures are considered as “planned”. Both scenarios are assumed to contain the 140g/km standard for new passenger cars. Furthermore, the same degree of implementation of the biofuel directive is assumed in Scenario S0 as in S1.

EU15, “EU10” and EU25

Data is often reported only for EU15 (e.g. Blok 2001a) rather than for EU25 (= EU 15 + “EU10”). This makes it necessary to upscale data from EU 15 to EU25. This is generally done by using the factor between the emissions in the baseline according to EEA 2005a, given per country for EU 15 and EU 25.

2.3. QUANTIFICATION: SCENARIO DEVELOPMENT

The starting point for quantitatively defining the GHG emissions (expressed as CO_2 equivalents) of the **baseline scenario (=S0)** is the baseline for 2010 presented in Blok et al. (2001b)[1]. This baseline scenario is described in relation to gases, sectors and countries. It is being compared to the EEA (2005) scenario by reviewing sector and GHG emissions. However, eventually the data were adjusted to the latest PRIMES baseline scenarios[2] and most recent information about the development of activities. (More details are given in chapter 7).

---

[1] Blok et al. (2001b) is the summary report for policy makers, made in collaboration between the Blok team and the team behind the PRIMES model.

[2] PRIMES is a partial equilibrium model for the European Union energy system developed and maintained at the National Technical University of Athens. PRIMES only takes into account the fuel related carbon dioxide emissions which correspond to about ¾ of the total GHG emissions. However these emissions can be separated in the baseline mentioned above and a comparison will be possible. A comparison directly between PRIMES and EEA

The procedure to define **scenario 1 (=S1)** is similar to the one for the baseline scenario. Starting point is the EEA (2005) scenario "with additional domestic policies and measures". The effects of these additional measures are then applied to the baseline scenario (S0). In this manner the relationship between S1 and S0 are compatible with EEA's scenarios. As particular element scenarios S0 and S1 also include the results from the special analyses for the road transport sector (see chapter 5).

2.4. CONSTRUCTING "MAC" CURVES

In order to identify the most efficient and least-cost mix of adaptation and mitigation actions over time to meet the EU environmental objectives it is necessary to identify in a first step the costs of greenhouse gases emission reductions of all relevant measures in different sectors in the timeframe 2008-2012. These are expressed as MAC (marginal abatement costs, expressed in €/t CO_2 equivalent). In a second step, based on the lists of measures and their MAC and reduction potential[3], sectoral MAC curves are constructed for each sector as follows:

1. As a first step, all policies and measures (PAMs [4]) in place (included in S0) and (separately) the planned measures (included in S1) are filtered out from the total list of measures per sector. This remaining list defines a MAC curve which includes all additional measures beyond implemented and planned measures which are already part of Scenario 1. Therefore we call these MAC curves PAM1+.
2. All measures are then ordered in ascending order of specific cost (€/Ton CO_{2eq}), along with their reduction potential (Mtonnes/a). Generally the first measures in this list will have negative[5] net cost. The highest cost measures are ordered at the end of the list. This data (MAC vs. emission reductions) is then plotted in a diagram with MAC (€/ton) on the vertical axis, and the sum of emission reductions (Mtonnes) on the horizontal. The result is a stepped curved, with each measure showing its contribution to emission reduction at its specific cost. The lowest cost measures appear on the left, and the highest cost measures on the right side of the diagram. Generally the curve gets steeper and steeper as one has to consider yet more expensive measures with decreasing reduction potentials, see Figure 1.

(2005) is more difficult because the fuel related carbon dioxide emissions cannot be extracted from their projections.

[3] Until the first Kyoto commitment period 2008/ 2012

[4] In many cases a PAM can be included *partially* in S0 or S1. This is, for example the case when a measure (such as building insulation) is included in S0 with a low implementation degree. S1 can then contain the same measure with an additional step in the degree of implementation, possibly at higher cost.

[5] Benefits due to energy and CO savings (plus possibly anxilliary benefits, e.g. environmental) are higher than the cost.

PROCESS OF CONTRUCTING SECTORAL MAC CURVES

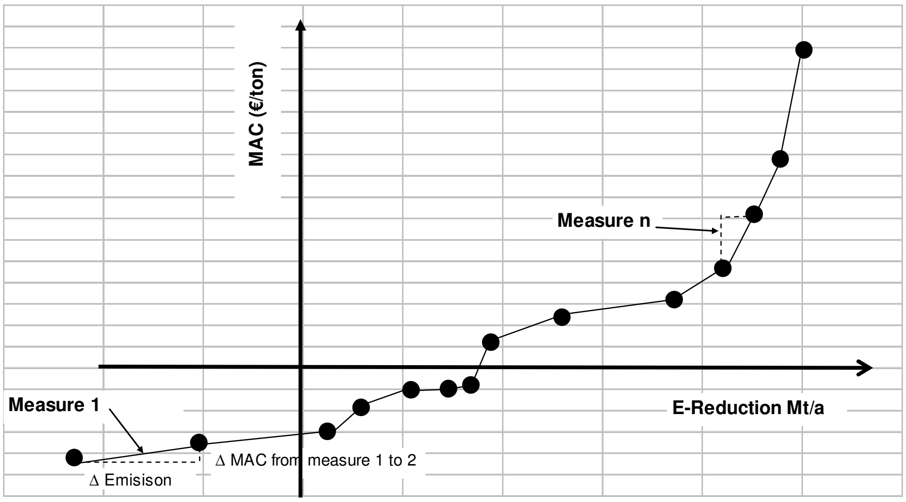


Figure 1: Schematic illustration of the process of contructing sectoral MAC curves based on the MAC data extracted from the literature by measure.

3. Once all the sectoral MAC curves[6] have been constructed they can be combined to the aggregated MAC curve for the EU25. For this purpose, the ordering procedure described above for the sectoral curves is now applied to the overall list of measures from all sectors, i.e. the ensemble of the sectoral MAC curves. The result is an order of measures, sequentially to be taken from all sectors: the most cost effective measures first (placed on the left in the diagram) and so on.

This curve is – by definition – a cost effective path under the assumption[7] that no measures have been forgotten which could make a reduction contribution at less cost than the most expensive measure at the far right of the diagram.

2.5. COMBINING SCENARIOS AND MAC CURVES

The following diagram illustrates qualitatively how scenarios and MAC curves are interrelated: Basline Scenario S0 ends up in 2010 at a certain point (in the illustration at 5038 Mtonnes CO_{2eq}/a), including “measures in place” at certain costs. Similarly for S1 which is assumed to end up in 2010 at 4834 Mtonnes CO_{2eq}/a, with certain MACs for these “planned” costs. For this

---

[6] ΔS0 relative to S0, and ΔS1 relative to S1.

[7] And the assumption that the degress of implementation and costs and benefits per PAM (adapted form Blok) reasonably reflect reality.

project however, only the reductions of the yellow area are relevant, i.e. the policies and measures yielding additional reductions beyond Scenario 1.

SCHMEMATIC GRAPH OF DIFFERENT SCENARIOS, MACS AND PAMS

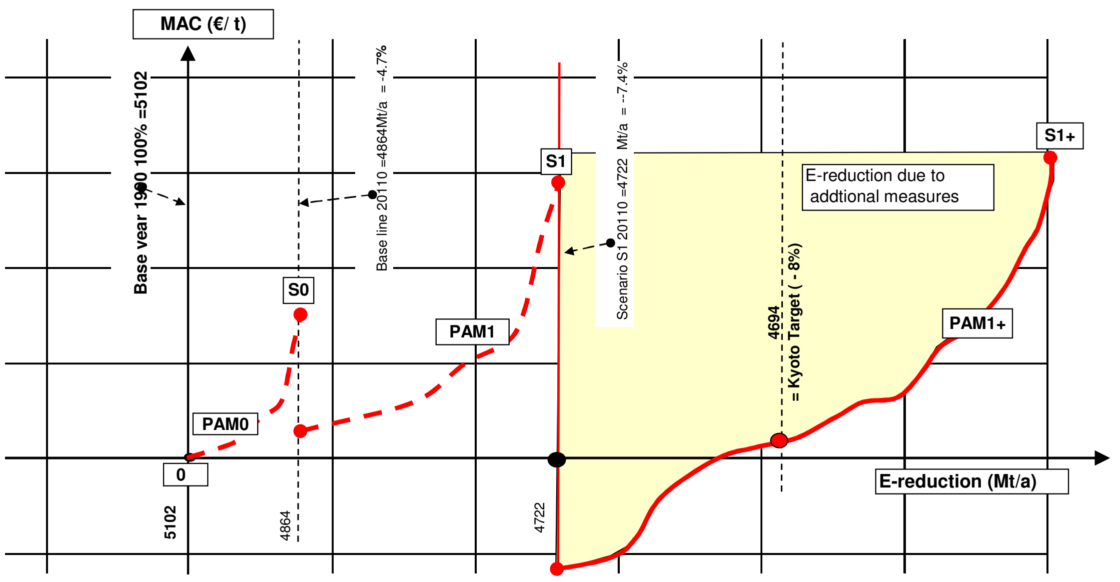


Figure 2 The graph shows the relationship between the MAC curves (due to PAM0, PAM1 and PAM1+) of the Basline Scenario S0 (with measures in place), Scenario S1 (with measures planned added) and reduction measures PAM1+ (with additional measures added). For this project only the yellow reductions are relevant. In chapter 4 only this MAC curve (PAM1+) is shown with scenario S1 as the reference point at 4722 Mtonnes CO_{2eq}/a.

2.6. METHODOLOGY FOR EXTRACTING MAC DATA PER SECTOR

Extracting and presenting MAC data

Based on the results of the main studies identified costs and emission reductions per PAM were reported in more detail (see section chapter 3, 4 and 5). This serves for the construction of MAC curves in each sector and for quantifying[8] the scenarios (see chapter 7). The focus here was clearly on Blok et al. (2001a) for MAC data, and EEA (2005, and 2006) as well as PRIMES for the scenarios.

---

[8] The quantification is based on the data extracted from earlier studies and adapted to this study. In many respects, this is much less than accurate. Therefore, the conclusions from this quantification is lead largely in a qualitative manner.

For this, a common methodological framework was defined to be followed by each sector. It defines uniform formats for extracting and representing PAM characteristics and MAC data from the studies.

A special rule is defined on how Blok's MAC data is to be assessed and possibly modified for use in the present study in each sector. Table 2 is defined for summarizing key data on one line per PAM:

		Data of orig. source		**Assessment**					
Name of measure, (and source)		**MAC €/ton**	**GHG Red. Mton CO_{2eq}/ a**	**Cate-gory 1, 1d, 2,3 or 4**	**CF1) appl. to**		**MAC €/ton**	**GHG Red. Mton CO_{2eq}/ a**	**Commment (Rational of classifi-cation)**
					MAC	**Red. Pot.**			

1) For the reduction potential (Red. Pot) the correction factor is a multiplier, generally smaller than 1 (mainly because of the shorter implementation time available from 2007 to 2010). For the MAC the CF can be a multiplier (dimensionless) or an "adder" (in €/t). If the MAC given by Blok is near zero, then a multiplier does not make much sense; hence an adder (or subtractor) value is used.

Table 2 Uniform format for assessing MAC and emission reduction data by measure, as extracted from the literature.

Correction factors CF are used to take into account corrections in the MAC or in the reduction potential (or the implementation degree assumed) reported by Blok for a particular measure.

- › **CF Reduction Potential:** Two types of correction factors CF are applied to the GHG
  - a) A global CF of 1.15 to transform reduction potentials from EU15 (Blok data) to our system EU25.
  - b) A PAM-specific CF to take account for the following criteria b1 and b2
    - b1) The shorter implementation time between 2007 and 2010 (3 years) for the present study, and 2000 to 2010 (relevant for the Blok data)
    - b2) Because Blok – from today's perspective – may have over- or underestimated the implementation barriers: in the first case a CF >1 is used, in the second a CF <1.
- › **CF MAC:** Here a CF (multiplier or adder /subtractor) is applied to reflect our assessment of the MAC by the Blok study.

a) Blok may have – from today's perspective- over – or underestimated the MACs in 2000/ 2001. If in our assessment Blok has estimated MACs too optimistically, this implies a CF of >1 (or a positive adder) for MAC data.
b) The technological progress which has occurred since 2000. This in general implies a MAC-CF of <1, or a negative adder.

For the concretely applied CFs for key PAMs we refer to the analyses in Chapter 4.1 and 4.2[9] . In the transport sector no CFs are used, because that data do not refer to Blok, rather to a more recent study for the passenger car subsector (TNO 2006, see chapter 5.1) resp. the data have been produced within this study for the HDV subsector (see chapter 5.2).

Additionally, since the Blok study relates to data of 1990 price levels, all cost data extracted from the Blok study, have been inflated by an EU weighted factor of 1.2 (based on the development of the industrial producers price index for EU 25 between 1990 and 2003).

The significant increase in fuel prices since 2001 (in particular since 2005) has been taken into consideration by adjusting cost data on the basis of the following energy prices:

ASSUMPTIONS ABOUT ENERGY PRICES			
	Blok et al. (2001a) prices	**Base case for this study**	**Sensitivity discussion and analysis**
Fuel (gasoline)	0.17 €/L	0.3 €/l	0.41 €/l
Oil (approx assumption, derived from prices above)	~20 €/bbl	36 €/bbl	50 €/bbl

Table 3 Energy prices used in this study.

2.7. EXTENDING THE EU ETS TO ROAD TRANSPORT

Eventually the project has to present the potential implications of extending the EU Emission trading scheme (ETS) to the road transport sector. Methodologically the following steps are performed:

1. The fundamental system parameters (institutional, substantive, organisational) for designing are discussed and assessed in view of extending the current EU- ETS[10] to road transport:

---

[9] Notable examples for important PAMs are NGCC in chapter 4.1; PAM Nr. 33 and 53 for the industrial sector in Chapter 4.2) and PAMs 8, 9 and 13 in the household sector (Chapter 4.2)

[10] The present ETS covers roughly 12000 installations (all in the EU15) , mainly in the industry and energy production sectors. Together they comprise about 50% of the CO_2 emissions in the EU25.

  - specific vs. absolute targets or caps
  - allocation procedures (grandfathering vs auctioning emission rights)
  - liable actors (downstream vs. upstream approach)
  - openness of the ETS system (geographically, and by sector)
2. The criteria for selecting a given ETS design are spelled out
  - economic, ecological, administrative, Kyoto-political etc
3. Adaption of a specific ETS design for the integration of road transport in the EU ETS
4. The potential effects of expending the EU ETS to cover car manufacturers is presented in more detail (on the basis of broad assumptions as to the possible design of such a system)

3. LITERATURE SEARCH

3.1. GENERAL STUDIES

As a first step literature was screened for studies and documents relevant to the project, covering all sectors and EU 25. The Annex to chapter 3 gives an overview of the literature screened. The annex also presents summaries of the content of the various studies and documents and indicates the usefulness for this project. This task provided an overview of relevant literature and allowed to set priorities in terms of which studies shall be used as data sources for the project.

Sources for MAC data

The result of this step revealed that there was one particular study – by Blok et al (2001 a and b) – which reported MAC data far more comprehensively and consistently than any other study identified. For this reason it was decided[11] to use Blok et al. as the «lead study» for extracting MAC data. This implies that Blok's data was used systematically as the primary source; and other studies and data were selectively used for plausibility checks and possible adaptations.

Sources for projections

As relevant source for projections of future GHG emissions in the EU were found to be presented in EEA (2005) where the scenario "with existing domestic policies and measures" corresponds to the definition of the baseline scenario (= scenario 0) in this study. However, newest information in the context of PRIMES (2005) was used for updating the baseline scenario. So the primary source for the baseline of this study eventually is PRIMES which uses the same sector structure as Blok et al (2001a and b).

For scenario 1 ("with planned measures") there was the intention to define a scenario that corresponds to the scenario "with additional domestic policies and measures" as defined in EEA (2005a), but has the same sector structure as PRIMES resp. (Blok 2001a) and which is consistent with the scenario 0 defined for this project. Therefore the main source for defining the relative reduction levels of scenario 1 compared to the baseline (which corresponds to the effect of the "planned" measures) was taken from EEA (2005). But transformation procedures had to be applied (see chapter 7) to match the differences in the sector structures.

3.2. SECTORAL STUDIES

The literature used for deriving sectoral information about policies and measures, about reduction potentials and costs varies from sector to sector. Therefore, the studies and documents re-

---

[11] In spite of the fact that the Blok study was not from a very recent date (published in 2001). The necessary adaption procedures were defined and applied in this project (see chapter 4 for details).

ferred to are indicated by sector in chapter 4 which deals with the relevant non-road sectors. While for the non-road sector the MAC data was derived from existing literature (in particular using Blok et al 2001b as lead study) and adapted if necessary, for road transport a different approach has been applied: for the light duty sector a recent study (TNO 2006) is the primary basis which reviewed technical and non-technical measures to achieve CO_2 reduction (see chapter 5.1). For the heavy duty sector no appropriate literature could be found providing cost effectiveness data in comparable form. Therefore several measures were analysed especially for this study (see chapter 5.2).

4. EMISSION REDUCTION POTENTIALS AND MACS BY SECTOR

As the study Blok et al. (2001a) is considered the lead study and therefore is the basis for the sectoral studies, we give as an introduction of the sectoral studies' summaries some explanations on how we used and adapted the figures from this study.

In Blok et al. (2001a), the reduction potentials of the various measures are estimated on the basis of a reference scenario for 2010. This reference scenario is called Frozen Technology Reference Level (FTRL) and corresponds to a situation where the economy and production growths are forecasted using PRIMES (1999) but without any technology improvement. With these assumptions the GHG emission level for 2010 is almost 30% higher in 2010 than in 1990. In this project, another baseline scenario is chosen that better corresponds to the probable situation in 2010 (according to EEA 2005a) and that is roughly in line with the emissions in 1990.[12]

The MAC data from Blok et al. (2001a) have been updated in several aspects in order to receive the policies and measures additional to the planned measures of scenario 1 (PAM1+):

1. The reduction potentials have been reduced, taking into account that only a few years are left until 2010, whereas Blok et al. (2001a) based the calculations of reduction potentials on an almost 10-year-period of implementation. The few years left from 2006 to 2010, will reduce the possibility to implement the full reduction potential as calculated by Blok et al. (2001a).
2. The reduction potentials have been reduced to correspond to the baseline scenario (scenario 0) and scenario 1 respectively.
3. The reduction potentials have been adjusted (increased) to apply to EU25, whereas Blok et al. (2001a) considered EU15 only. Therefore sector specific correction factors[13] are calculated from the emission differences between EU15 and EU25 for the different sectors. These correction factors are used to up-scale the reduction potential for the MAC-data from EU15 to EU25.

---

[12] The total emissions for EU15 are about the same. However, the individual sectors have changed significantly (some have increased, whereas some have decreased).

[13] Correction factors used to upscale emission potentials from EU15 to EU25: Energy supply (CO_2 related), distributed as indirect emissions to all sectors: 1.27, energy supply (non CO_2 related GHG emissions): 1.28, fossil fuel extraction, transport and distribution: 1.28, industry: 1.25, households: 1.19, services: 1.22,; agriculture: 1.31, waste: 1.26, transport as a total: 1.11, whereof road transport: 1.10 (public road transport: 1.18, motorcycles: 1.05, private cars: 1.10, trucks: 1.10), rail transport: 1.31, national aviation: 1.04, inland navigation: 1.01.

4. The marginal abatement costs have been adjusted according to the rate of inflation from 1990 (the year used in Blok et al. 2001a) to 2003 (the year used in this project). The inflation has been 21.2% between 2003 and 1990. The correction factor ($CF_{inflation}$) is then 1.212.
5. The emission potentials described by Blok et al. (2001a) have been individually adjusted if necessary because they are thought to be too high or too low. In some cases (i.e. in the agricultural sector) some measures had to be disregarded because their implementation does not seem to be realistic until the Kyoto period and/or because they produce leakage or other serious side effects.

The change in reduction potentials due to the short time frame left until 2010 (point 1 above) has been performed by implementing a correction factor (CF_{time}). CF_{time} is expressed as the percentage of the reduction potential in Blok et al. (2001a) that still is considered possible to implement in relation to the short time frame between 2006 and 2010.

4.1. ENERGY SUPPLY (IFEU)

(1) Literature

According to the decision for the overall project Blok et al. (2001a) is used as the lead study. Generally for the update a lot of studies, articles etc. on energy efficiency, costs etc. could be used. With respect to the limitations of the project as well as the reliability of the updated data a selection of four recent comprehensive studies are used.

- DLR et al. (2004): focus on renewables and Germany (abatement costs are not adopted directly but assessed from this source)
- FFE (2004): electricity from fossil, nuclear and renewable resources, focus on Germany (abatement costs are not adopted directly but assessed from this source)
- IFEU (2004): biofuels for transportation, world
- VIEWSL (2006): biofuels for transportation in Europe

(2) Measures

For the energy supply sector the following categories of measures/processes and pollutants are considered in Blok et al. (2001a).

- Coal mining and natural gas transport: methane
- Refineries: CO_2

- Electricity and heat/steam production: CO_2
- Electricity distribution: SF_6
- Fluidised bed combustion: N_2O

For the update no additional measures are considered. From our point of view none of the other technologies which will be important in the future (fuel cells of different concepts e.g.) will contribute significantly within the next four to six years to GHG abatement. The measures are discussed below.

(3) Achievable emissions reductions (2010) and marginal abatement costs

In the following at first measures and data according to Blok et al. (2001a) are discussed. In the next section the adaptation to the EU25 and the smaller time range (2006 to 2010 instead of 2000 to 2010) as well as different assessments of potentials are presented.

Coal mining and natural gas transport: methane

The reduction potential of the supply of fossil fuels according to Blok et al. (2001a) is connected with only 6 measures and quite small compared to other energy sub-sectors. Because of the low specific costs or even savings of degasification of coal mining with established technologies it is probably that the measures will be implemented to high extent till 2010. However, the European coal production today is lower than 1990/95. Therefore the overall effect is very uncertain. The biggest potentials are linked with improvements of the natural gas transport including replacement of old pipelines which, however, is one of the two most expansive measures.

Refineries: CO_2

For refineries 5 measures or bundles of measures are given in Blok et al. (2001a). 4 of them lead to cost savings or very low specific costs. Probably they will be implemented by fitting, maintenance and in new plants etc.

Electricity and heat/steam production: CO_2

For this (sub-)sector 4 categories of measures are considered:

- NGCC (natural gas combined cycle): replacement of coal fired power plants by NGCC plants and NGCC for additional power demand.
- CHP (combined heat and power production): increased use of CHP based on natural gas. (Partly) Substitution of NGCC is assumed in Blok et al. (2001a). It is important to note that the

overall potential is strongly affected by the choice of the reference. The potential would be much higher in reference to e.g. coal fired plants.

- Increased use of renewable energy (biomass, wind, hydro (incl. tidal), geothermal and solar photovoltaic energy). As for CHP a partial substitution of NGCC is assumed in Blok et al. (2001a) (see the note above).
- CO_2 removal: Principally capture and storage of CO_2 can be applied to all processes producing CO_2. In Blok et al. (2001a) the application at new power plants is assumed.

NGCC: The implementation is the measure with by far the biggest potential. The replace-ment of 50% of the coal plant capacity from 1995 to 2010, however, seems to be too high. The efficiency of 55% as a mix of plants of different sizes and different loads etc. is realistic. The outcome of "no net costs" because of the high efficiency and less expensive flue gas cleaning is extremely sensitive regarding the future fuel prices, load etc.

CHP: Data for CHP are given in a very detailed form for a long list of applications and pattern of use. For the complete implementation in all sectors the average abatement costs for 1 t of CO_{2eq} are 140 Euro; the range is 12 to 398 Euro.

Renewables: As mentioned above very different technologies are covered. For biomass for heat or CHP savings or cost below 20 Euro / t CO_2 are given. The highest potential of all renewables is assumed for heat from solid biomass. Use of liquid biofuels is one of the most expensive measures.

CO_2 removal: As underlined in Blok et al. (2001a) the estimation of the potentials of CO_2 removal is not straightforward. With respect to the assumed high potential it is important to keep in mind the high uncertainties.

Electricity distribution: SF_6

For the recovery of SF6 from gas insulated switchgears potentials and cost are small.

Fluidised bed combustion: N_2O

Potentials and cost are small. In Blok et al. (2001a) the relevance of FBC is assessed to be small. The data according to Blok et al. (2001a) are listed in the tables below together with the updated potentials and costs (section 4: energy summary).

As discussed above it is not possible in the scope of the project to generate consistent energy balances and forecasts. Instead of this assessments of updated potentials and costs (including inflation) are done as described in section 2.6.

The literature evaluation and adaptation work is focused on measures with high potentials. The updated potentials and costs are listed together with the data according to Blok et al. (2001a) in the tables below (section 4: energy summary). According to Blok et al. (2001a) data for "fossil fuel supply" and "energy supply" (conversion and distribution) are documented separately. For the energy supply comments on the assessment of the specific costs are given in the table. Some more general comments are given below.

Comments on the MAC of fossil fuel extraction

For none of the considered measures sound data for a modification are on hand. Because of the small overall contribution no in-depth search for other data was done, i.e. the specific costs according to Blok et al. (2001a) should be used in the ongoing project without specific modifications (only inflation is considered). Potentials are adapted to EU25 and the considered time period.

Comments on the MAC of energy supply

Specific abatement costs

The modifications done here are based on the bandwidth of CO_2 or (!) CO_{2eq} data in the sources mentioned above. Modifications are made mainly if the value according to Blok et al. (2001a) is out of the range of the considered alternative sources. Usually the end of the range closer to the data from Blok et al. (2001a) is to be considered as the relevant value. If the value from Blok et al. (2001a) is within the range of other sources but very close to the minimum or maximum the value is corrected in the direction to the mean of the range. A lot of measures are classified "1" because the amounts of their MACs (positive or negative) are very small, i.e. the modification factors must be large for achieving small absolute modification amounts.

Modifications of the MAC of NGCC and biofuels for transportation raise the overall costs for achieving the assumed reduction potential - *without adaptation of the time period (!)* - for more than 50%. Sensitivity analyses are necessary! Because of small reduction potentials and no other data being on hand for modifications, data on measures dealing with refinery processes and non-CO_2 GHG according Blok et al. (2001a) are not modified.

Potentials

For all measures - except NGCC - only the adaptations for EU25 and the considered time period are applied. Even there is an increasing share of NGCC in power production the assumptions of Blok et al. (2001a) seems to be much too optimistic. 50% of the formal adopted (EU25, time period) Blok et al. (2001a) potential is proposed here.

Overall assessment

Applying correction factors on existing energy balances and forecasts are the cheap and easy but rough alternative to the compilation and derivation of new balances and forecasts. Unavoidable this simplified procedure is less consistent and more arbitrary.

Focusing on NGCC: Therefore there is no strong scientific reason for the reduction of the potential of NGCC according (Blok 2001a) by 50% (additional to factors for inflation, EU15 to EU23 and smaller reference time period). This value reflects in a general way that - in contrast to the assumptions in (Blok 2001a) - not only NGCC but also reasonable numbers of large coal and lignite power plant are under construction or planned. On the other side there is no doubt that NGCC will be very important in the future. However, evaluation of the plans of electricity provider etc. for more sound data cannot be done in the frame of the project. Overall 50% of the formal adopted (EU25, time period) seems to be an optimistic but not unrealistic value.

Generally: All the modifications are very rough estimates. The data should be used only in the ongoing project.

(4) Summary: Cost effective emissions reduction within the sector (Marginal abatement cost curve)

The data according to Blok et al. (2001a) and the updated potentials and costs are listed together in the tables and presented in the MAC graphs below. The data are derived from (Blok 2001a) as follows (examples):

Biomass (cultivated) 3a: Heat only on solid biomass

Reduction potential: 40% (CF shorter implementation time) * 1,15 (CF EU15 => EU25) * reduction potential (Blok 2001a)

MAC: 50% (CF lower costs based on (DLR et al. 2004)) * 121% (Inflation) * MAC (Blok 2001a)

NGCC:

Reduction potential: 40% (CF shorter implementation time) * 1,15 (CF EU15 => EU25) * 50% (estimated CF; (Blok 2001a) much too optimistic) * reduction potential (Blok 2001a)

MAC: adder on value from (Blok 2001) (0 Euro), calculated based on (FFE 2004), including inflation

Table 4 summarises the most important or largest individual modifications. Evidently the assessment of costs and potentials of NGCC is extremely important for a sound overall MAC curve (combination of very large potential in spite the reduction and – at least relatively – large modification of specific costs). Therefore a sensitivity analysis is strongly recommended. Considering the updated data NGCC and biofuels cause more than half of the overall costs.

Measure	**MAC**		**Potentials**		**Overall costs**			
	Orig.	**Assess.**	**Orig.**	**Assess.**	**Orig.**	**Assess.**	**Orig.**	**Assess.**
	EURO / t CO_{2eq}		**Mtonnes CO_{2eq}**		**M Euro**		**Shares**	
NGCC	0	16	500	127	0	2.078	0%	10%
Biomass 4b: biodiesel	299	544	24	12	7.176	6.627	31%	32%
Biomass 4a: ethanol	236	665	9	5	2.124	3.040	9%	15%
Other			334	170	13.700	8.788	60%	43%
Total			867	313	23.000	20.533	100%	100%

Table 4 Important individual contributions on potentials and/or costs in the energy supply sector (Calculation example NGCC see above)..

No.	**Measure**	**Blok et al. (2001a)**		**Assessment**			
		MAC	**GHG Red.**	**Cate-gory**	**CF**	**MAC**	**GHG Red.**
		Euro / t CO_{2eq}	**Mtonnes CO_{2eq}**			**Euro / t CO_{2eq}**	**Mtonnes CO_{2eq}**
1	Various improvements of compressors Compressors	-4	0.4	(3)	1	-4.85	0.20
2	Inspection and maintenance - power equipment Energy requirements	-4	0.1	(3)	1	-4.85	0.05
3	Increased gas utilisation Process vents/flares	-1	0.1	(3)	1	-1.21	0.05
4	Coal mining degas ification (low and medium recovery rate) Coal mining	-1	6	(3)	1	-1.21	3.07
6	Coal mining degas ification (medium recovery rate) Coal mining	0.1	2	(3)	1	0.12	1.02
7	Coal mining abatement from ventilation air Coal mining	1	0.6	(3)	1	1.21	0.31
8	Reducing flaring/venting emissions related to associated gas Associated gas	2	0.2	(3)	1	2.42	0.10
9	Utilisation of process vents and other options Various oil and gas	10	0.2	(3)	1	12.12	0.10
11	Offshore flaring instead of venting of process vents Process vents/flares	21.4	0.1	(3)	1	25.94	0.05
12	Replacement grey cast iron network low Fugitive emissions	36	10	(3)	1	43.63	5.12
15	Increas ing the pipeline examination frequency Fugitive emissions	77	4	(3)	1	93.32	2.05
16	Replacement grey cast iron network high Fugitive emissions	80	10	(3)	1	96.96	5.12
14	Various options: compressors. associated gas. system upsets Various oil and gas	82.5	0.4	(3)	1	99.99	0.20
	Total emission reduction potential		34.1				17.5

Table 5 Fossil fuel supply: emission reduction potentials and costs of measures according to Blok et al. (2001a) and this study (for details see text) Original source: Blok et al. (2001a) fossil fuels (Summary), p. III.

No.	Measure	Blok et al. (2001a)		Assessment				
		MAC	GHG Red.	Cate-gory	CF	MAC	GHG Red.	Comment
		Euro / t CO_{2eq}	Mtonnes CO_{2eq}			Euro / t CO_{2eq}	Mtonnes CO_{2eq}	
1	Refineries: Reflux overhead vapour recompression (distillation)	-66	6	(3)	1	-80	3	see text
2	Refineries: Power recovery (e.g. at fluid catalytic cracker)	-51	1	(3)	1	-62	1	"
3	Biomass (waste) 1b: CHP on solid biomass	-34	4	3	1	-41	2	good agreement to data calculated from DLR et al. (2004)
4	Biomass (waste) 3b: Heat only on solid biomass	-42	25	2	0.7	-36	13	modification based on data calculated from DLR et al. (2004) (minmum)
5	Refineries: Miscellaneous I (Low cost tranche)	-29	6	(3)	1	-35	3	see text
6	Refineries: Improved catalysts (reforming)	0	4	(3)	1	0	2	"
7	SF_6 Recovery from gas insulated switchgears	3	1	(3)	1	4	1	"
8	N_2O Combustion processes fluidised bed after burner	3	1	(3)	1	4	1	"
9	N_2O Combustion processes fluidised bed reversed air staging	4	1	(3)	1	5	1	"
10	Wind energy – onshore	3	30	1	2	7	15	modification based on data calculated from DLR et al. (2004) (minmum)
11	Biomass (cultivated) 3a: Heat only on solid biomass (calculation see text)	15	64	4	0,5	9	33	modification based on data calculated from DLR et al. (2004) (average)
12	NGCC (calculation see text)	0	500	2	-	16	127	modifications very crucial; proposal (sensitivity analyses necessary): MAC = 50% of minimum calculated from FFE (2004) (costs or savings according to Blok et al. (2001a) seems very optimistic; probably gas prices to low in Blok et al. (2001a); on the other side at least maximum in FFE (2004) is very high because of low mean load)
13	Large hydropower	11	15	1	2	27	8	modification based on data calculated from DLR et al. (2004) (minmum)
14	Biomass 2: CHP anaerobic digestion	-23	4	1	-	27	2	modified MAC = minimum calculated from DLR et al. (2004)

No.	Measure	Blok et al. (2001a)		Assessment				
		MAC	GHG Red.	Cate-gory	CF	MAC	GHG Red.	Comment
		Euro / t CO_{2eq}	Mtonnes CO_{2eq}			Euro / t CO_{2eq}	Mtonnes CO_{2eq}	
15	Small hydropower	10	2	1	3	36	1	modification based on data calculated from DLR et al. (2004) (minmum)
16	Biomass (cultivated) energy 1a: CHP on solid biomass	20	29	1	2	48	15	modification based on data calculated from DLR et al. (2004) (average)
17	CO_2 removal and storage	50	50	(3)	1	61	25	no consistent alternative data on hand (only single values)
18	Geothermal electricity production	53	2	(3)	1	64	1	no consistent alternative data on hand (only single values)
19	Refineries: Miscellaneous II (High cost tranche)	60	6	(3)	1	73	3	see text
20	Wind energy – offshore	88	18	4	0,8	85	9	modification based on data calculated from DLR et al. (2004) (maximum)
21	Tidal energy	118	2	(3)	1	143	1	no alternative data
22	CHP	140	62	(3)	1	170	31	acceptable agreement to data calculated from FFE (2004)
23	Solar power: photovoltaic energy	308	1	3	1	373	1	assuming big influence of southern countries in Blok et al. (2001a) no modification based on data for Germany
24	Biomass 4b: biodiesel	299	24	2	1.5	544	12	modification based on bandwidth in IFEU (2004) and reference in VIEWLS (2006)
25	Biomass 4a: ethanol	236	9	1	-	665	5	modified MAC = mean of 7 reference data (overall 2 technologies, 2 technology levels, 4 resources) adopted from VIEWLS (2006)
	Total emission reduction potential		867				313	

Table 6 Energy supply: emission reduction potentials and costs of measures according to Blok et al. (2001a) and this study (details and calculation for NGCC see text).
Original source: Blok et al. (2001a) energy supply, p. 42; other sources: DLR et al. 2004, FFE 2004, IFEU 2004, VIEWLS 2006.

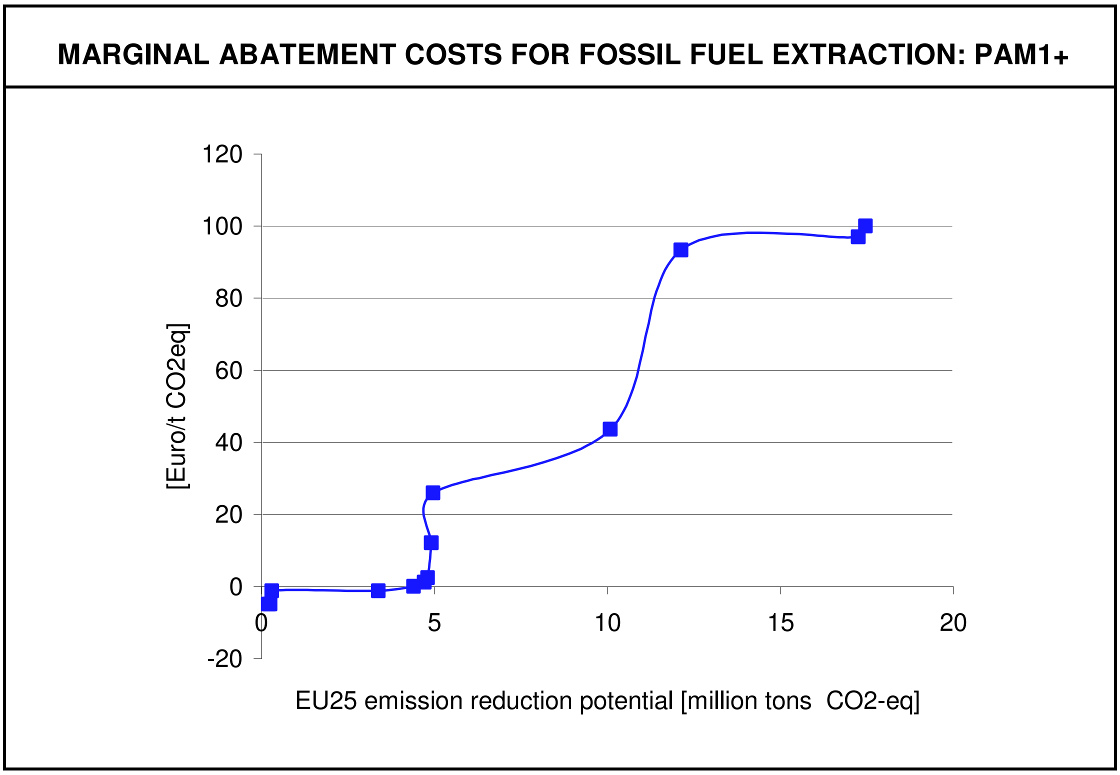


Figure 3 Fossil fuel extraction: MAC curve for PAM1+ for EU25 (additional policies and measures beyond the planned measures of scenario 1: for details see text and Table 6 which can be used as a legend for the figures).

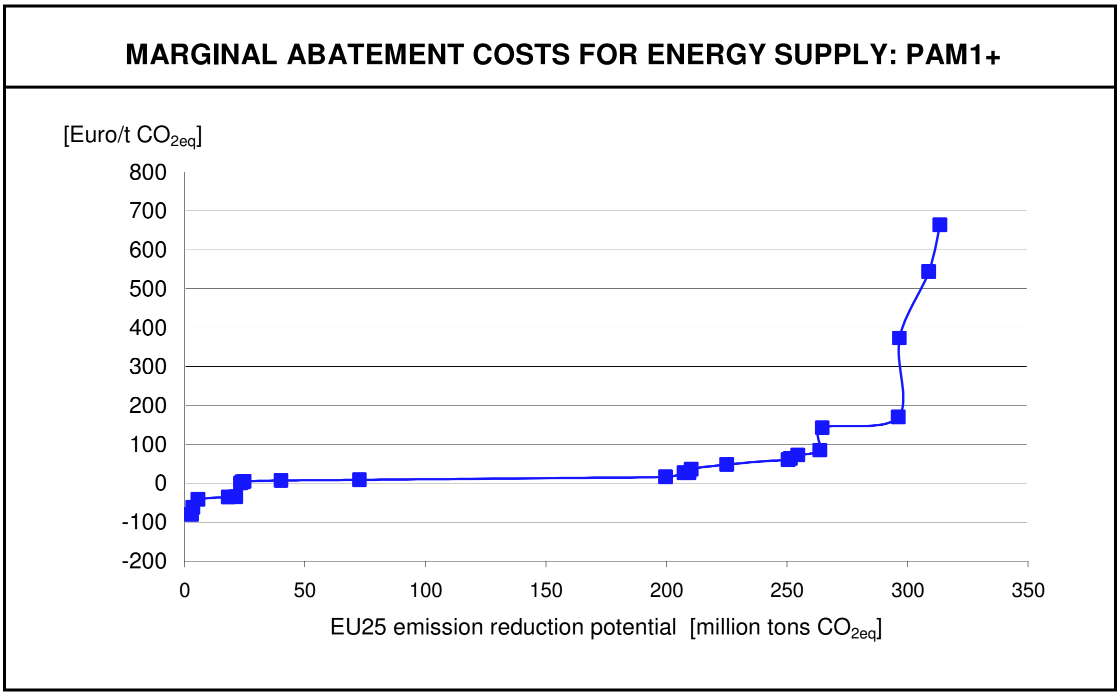


Figure 4 MAC curve for additional policies and measures beyond the planned measures of scenario S1 of the energy supply sector for EU25. For details see text and Table 6 which can be used as a legend for the figure.

4.2. MANUFACTURING INDUSTRY, HOUSEHOLD AND SERVICE (IVL)

(1) Literature

The main literature reference has been Blok et al. (2001a) and the associated sector studies (de Beer and Phylipsen 2001 and Joosen and Blok 2001)[14]. Other literature references used to validate the Blok et al. (2001a) study are Ekström et al.(2006), Holmgren et al.(2005), Holmgren et al. (2006) and Stripple et al. (2005). However, different assumptions, different baselines and lacking background information have made the validation difficult.

(2) Measures

Some measures for the manufacturing industry, households and services are listed in Table 7, Table 8 and Table 9. All measures for these sectors are listed in the annexes. The tables (in the annexes) with the measures include data for the following three cases of PAMs:

› **PAM0+:** use the baseline scenario (scenario 0 = S0) as baseline. The measures in case 1 will therefore reduce the emissions from the emission level in scenario 0.

› **PAM1+:** use scenario 1 as baseline. The measures in case 2 will therefore reduce the emissions from the emission level in scenario 1.

› **PAM1+ ETS:** also use scenario 1 as baseline. However, in case 3, only measures compatible with emission trading are included.[15]

The marginal abatement costs are the same in all three cases. However, the reduction potential varies and is lower for PAM1+ than for PAM0+, as it is assumed that more measures have been implemented in scenario 1 compared to the baseline scenario (scenario 0). PAM1+ ETS include only those policies and measures from PAM1+ that are considered compatible with the EU ETS[16], and consequently the reduction potential is even lower.

The MAC curves for the policies and measures additional to scenario 1 (PAM1+) are presented in Figure 5 (manufacturing industries), Figure 6 (households), and Figure 7 (services).

---

[14] In this chapter all three reports are referred to as Blok et al 2001

[15] The EU ETS only includes CO_2 and only affects some sectors. Therefore only measures affecting CO_2 emissions in the EU ETS are included.

[16] See the footnote above.

(3) Achievable emission reduction (2010) and marginal abatement costs

The Blok et al. (2001a) study has been the main source of information on measures for GHG reductions including marginal abatement costs and reduction potentials. Some additional references have been used to validate the data in Blok et al. (2001a) study. The assessment of the Blok et al (2001a) study has been done by applying correction factors (CF) on the MAC-data and the reduction potential (red. pot.) according to the methodology outlined in chapter 2.6. Table 7, Table 8 and Table 9 provide an overview of the assessment of the most important measures in the three sectors: Manufacturing Industry, Household and Service. Equation 4-1 and 4-2 describe how the correction factors have been used in the assessment. All measures and the corresponding correction factors can be found in appendix. The different correction factors used for these sectors are described thoroughly below.

The change in reduction potentials due to the short time frame left until 2010 has been performed by implementing a correction factor (CF_{time}). CF_{time} is expressed as the percentage of the reduction potential in Blok et al. (2001a) that still is considered possible to implement in relation to the short time frame between 2007 and 2010. The methodology used to determine the CF_{time} is based on the estimation that behaviour measures to higher degree are possible to implement in a short time frame than measures associated with very large investments. The value of CF_{time} for each measure is listed in the annex. In the methodology for determining CF_{time}, other correction factors have been considered as well, i.e. $CF_{scenario\ 0}$ and $CF_{scenario\ 1}$ as explained below.

The change in reduction potentials due to selection of other baselines has been performed by implementing the correction factors $CF_{scenario\ 0}$ (for the change between FTRL[17] and scenario 0 = baseline scenario) and $CF_{scenario\ 1}$ (for the change between FTRL and scenario 1). $CF_{scenario\ 0}$ and $CF_{scenario\ 1}$ are expressed as the percentage of the reduction potential in Blok et al. (2001a) still available for implementation in relation to the other baselines used in this report (scenario 0 respectively scenario 1). The methodology for determining these correction factors has been to assume that the difference in emissions for each sector between FTRL and scenario 0 respectively scenario 1 totally depend on the measures in Blok et al. (2001a)[18]. However, in the emis-

---

[17] FTRL: Frozen Technology Reference Level.

[18] The total difference between direct emission levels in FTRL and scenario 0 for a particular sector corresponds to the total amount of reduced reduction potential (reduced by the CFscenario 0) for all measures in that sector. This implies that the difference between FTRL and scenario 0 is a result of complete or partial implementation of the measures defined in Blok et al (2001a). A consequence of this assumption is that no other measures than those listed in Blok et al (2001a) have been used for reducing the emissions from the FTRL to the scenario 0. The explanation is valid for scenario 1 as well.

sions for each sector both direct and indirect emissions are included[19]. Some of these emissions are reduced by measures taken in the energy supply sector and some are reduced by measures in the demand sectors (mainly manufacturing industry, household, and service). The reduction potentials for the measures (as listed in the annex) in the demand sectors do not include emission reductions in the energy supply. Therefore, the whole difference in emissions between the FTRL and the scenario 0 and scenario 1 respectively cannot be accounted to the measures implemented in the respective demand sector[20]. The size of the part stemming from measures taken in each sector has been determined by comparing the total reduction potential of all measures in each sector in Blok et al. (2001a) to the provided figure of the effect of the measures in the energy supply in each sector. According to this procedure 52% of the difference between FTRL and scenario 0 respectively scenario 1 depend on measures implemented in the manufacturing industry and 48% depend on measures implemented in the energy sector. The corresponding numbers for households is 48% and 52% and for services 45% and 55%.

The values of $CF_{\text{scenario 0}}$ and $CF_{\text{scenario 1}}$ for each measure have been based on the effects of implemented policies and measures (EU 2006) and by the assumption that the cheapest measures are implemented first. The $CF_{\text{scenario 0}}$ and $CF_{\text{scenario 1}}$ have finally been adjusted so the total effect of reduction of the measures' reduction potential correspond for each sector to the difference between FTRL and scenario 0 (baseline scenario) respectively scenario 1 as described above. The values of $CF_{\text{scenario 0}}$ and $CF_{\text{scenario 1}}$ for each measure are listed in the annex.

The potentials have been reduced even more within the EU ETS system, where only policies and measures compatible with emissions trading have been considered (PAM1+ ETS). The reason is that only policies and measures reducing CO_2 emissions and only measures reducing emissions in the sectors included in the EU ETS (European Emission Trading Scheme) are included in this PAM case. With these limitations, all measures in the manufacturing industry that reduce CO_2 will fully be part of the EU ETS, including the measures that reduce indirect emissions by e. g. decreasing electricity consumption. For some measures in the households and services sectors that reduce both direct and indirect emissions (e.g. by insulation), the potential within the EU ETS will be reduced by 50%. The correction factor $CF_{\text{EU-ETS}}$ expresses the per-

---

[19] Direct emissions are emissions from fuels used in the sector including processing emissions. Indirect emissions are CO_2 emissions related to electricity and heat used in the demand sectors (mainly manufacturing industry, households and services).

[20] The difference in emissions between FTRL and scenario 0 respectively scenario 1 includes both direct and indirect emissions, whereas the measures in the demand sectors (industry, households and services) only include direct emissions. Therefore, the proportion of direct emissions in the difference between FTRL and scenario 0 has been calculated.

centage of the reduction potential for PAM1+ that still can be used if an analysis of EU ETS is added (PAM1+ ETS).

Blok et al. (2001a) only comprises EU15. To adjust the reduction potentials to EU25, the reduction potentials are increased by a correction factor ($CF_{EU15\text{-}EU25}$), which has been determined for every sector by dividing the emissions in scenario S1 for EU25 with the emissions in scenario S1 for EU15. The $CF_{EU15\text{-}EU25}$ for manufacturing industries is 1.25, for household 1.19, and for service 1.22 (see also the introduction to chapter 4 for the correction factors of all the sectors).

The total correction factor used for assessing the reduction potential for "PAM1+" (that use scenario 1 as baseline) is calculated according to equation 1. The equation describes how the different correction factors above are used for calculating the total correction factor. The assessed reduction potential for "PAM1+" is then calculated according to equation 2. The correction factors in this formula and the assessed GHG reduction potential for the most important measures are described in Table 7, Table 8 and Table 9.

$$CF_{total\_red\_assessed} = CF_{EU15-EU25} * \left(CF_{scenario\_1} - \left(1 - CF_{Time}\right)\right) \qquad \text{(Equation 4-1)}$$

$$GHG\_\mathrm{Red}_{assessed} = CF_{total\_red\_assessed} * GHG\_\mathrm{Red}_{Blok} \qquad \text{(Equation 4-2)}$$

Table 7 Five examples of assessments and comments for the industry sector. Assessments for all measures can be found in the appendix. All data has been recalculated with respect to expansion from EU15 to EU25 ($CF_{EU15->EU25}$ = 1.25 for all measures in the industry sector), as well as inflation (1.212 for all measures). The correction factor for inflation affects the cost, whereas the other correction factors affect the reduction potential.

	Data of orig. source		**Assessment**					
All measure originate from the sector report of Blok (2001a)	**MAC (Blok, 2001a)** **€$_{1990}$/ton**	**GHG Red.**[21] **Mtonnes CO_{2eq}/a**	**Cate-gory*2**	**CF_{time}** **(% left for reduction potential)**	**$CF_{scenario\ 1}$**	**MAC**[22] **€$_{2003}$/ton**	**GHG Red.**[23] **Mtonnes CO_{2eq}/a**	**Comment**
33 Miscellaneous II (High cos ttranche)	-22	54	-	80%	40%	-27	13.5	The measure is cheap and 60% of the measure stated in Blok (2001a) is assumed to be implemented in scenario 1. Only 80% of the reduction potential is assumed to be available for implementation before 2010 due to the limited time left.
53 Industrial processes Nitric acid	0.4	22	-	70%	90%	0	16.5	The measure is relatively cheap but only 10% of the measure stated in Blok (2001a) is assumed to be implemented in scenario 1. 70% of the reduction potential is assumed to be available for implementation before 2010 due to the limited time left. According to equation 4-1 the total CF is calculated by reducing the 70% left according to the CF_{time} with the 10% (100%-90%) that is already implemented and multiply it (the 60%) by 1.25 to take into account the difference between EU15 and EU25 ($CF_{EU15->EU25}$).
70 S emiconductors: Chemical vapour depos ition (CVD), NF3	28	10	-	70%	90%	34	7.5	10% of the measure stated in Blok (2001a) is assumed to be implemented in scenario 1. 70% of the reduction potential is assumed to be available for implementation before 2010 due to the limited time left.
71 Heat recovery in TMP	31	7	-	70%	95%	38	5.7	5% of the measure stated in Blok (2001a) is assumed to be implemented in scenario 1. 70% of the remaining reduction potential is assumed to be available for implementation before 2010 due to the limited time left.

---

[21] Emission reduction potential in EU15 with the FTRL (2010) as baseline (Blok, 2001a).

[22] The MAC-data are updated due to the inflation that has occurred between 1990 and 2003 (21.2%) according to the methodology in chapter 2.6.

[23] Emission reduction potential in EU25 with the scenario 1 (2010) as baseline.

Table 8 Three examples of assessments and comments for the household sector. Assessments for all measures can be found in the appendix. All data has been recalculated with respect to expansion from EU15 to EU25 ($CF_{EU15->EU25}$ = 1.19 for all measures in household sector), as well as inflation (1.212 for all measures). The correction factor for inflation affects the cost, whereas the other correction factors affect the reduction potential.

All measure originate from the sector report of Blok (2001a)	**Data of orig. source**		**Assessment**					
	MAC (Blok, 2001a) €$_{1990}$/ton	**GHG Red.[24] Mtonnes CO$_{2eq}$/a**	**Cate-gory*2**	**CF$_{time}$ (% left for reduction potential)**	**CF$_{scenario\ 1}$**	**MAC[25] €$_{2003}$/ton**	**GHG Red.[26] Mtonnes CO$_{2eq}$/a**	**Comment**
8 Retrofit houses: wall insulation	-42	28	-	80%	60%	-51	13.3	About half of the reduction potential according to Blok (2001a) is assumed to have been implemented. 80% of the reduction potential is assumed to be available for implementation before 2010. According to equation 4-1 the total CF is calculated by reducing the 80% left according to the CF_{time} with the 40% (100%-60%) that is already implemented and multiply it (the 40%) by 1.19 to take into account the difference between EU15 and EU25 ($CF_{EU15->EU25}$).
9 Retrofit houses: roof insulation	-29	26	3	80%	50%	-35	9.3	About half of the reduction potential according to Blok (2001a) is assumed to have been implemented. 80% of the reduction potential is assumed to be available for implementation before 2010.
13 Retrofit houses: (highly) insulated windows	10	49	3	30%	80%	12	5.8	1 / 5 of the reduction potential according to Blok (2001a) is assumed to have been implemented. 30% of the reduction potential is assumed to be available for implementation before 2010. Windows are not changed very frequently and it takes time before the full potential is implemented.

---

[24] Emission reduction potential in EU15 with the FTRL (2010) as baseline (Blok, 2001a).

[25] The MAC-data are updated due to the inflation that has occurred between 1990 and 2003 (21.2%), according to the methodology in chapter 2.6.

Table 9 Two examples of assessments and comments for the service sector. Assessments for all measures can be found in the appendix. All data has been recalculated with respect to expansion from EU15 to EU25 ($CF_{EU15\text{->}EU25}$ = 1.22 for all measures in service sector), as well as inflation (1.212 for all measures). The correction factor for inflation affects the cost, whereas the other correction factors affect the reduction potential.

	All measure originate from the sector report of Blok (2001a)	**Data of orig. source**		**Assessment**					
		MAC (Blok, 2001a)	**GHG Red.**[27]	**Cate-gory*2**	**CF_{time}**	**$CF_{scenario\ 1}$**	**MAC**[28]	**GHG Red.**[29]	**Comment**
		€$_{1990}$/ton	**Mtonnes CO_{2eq}/a**		**(% left for reduction potential)**		**€$_{2003}$/ton**	**Mtonnes CO_{2eq}/a**	
6	Building Energy Management Systems (BEMS): space heating and cooling	-129	42	-	100%	15%	-156	7.7	85% of the reduction potential according to Blok (2001a) is assumed to be already implemented because the measure is cheap. All of the remaining reduction potential is assumed to be available for implementation before 2010. According to equation 4-1 the total CF is calculated by reducing the 100% left according to the CF_{time} with the 85% (100%-15%) that is already implemented and multiply it (the 15%) by 1.22 to take into account the difference between EU15 and EU25 ($CF_{EU15\text{->}EU25}$).
9	Retrofit services buildings: (highly) insulated windows	35	31	3	100%	15%	42	5.7	85% of the reduction potential according to Blok (2001a) is assumed to be already implemented. All of the remaining reduction potential is assumed to be available for implementation before 2010.

---

[26] Emission reduction potential in EU25 with the scenario 1 (2010) as baseline.

[27] Emission reduction potential in EU15 with the FTRL (2010) as baseline (Blok, 2001a).

[28] The MAC-data are updated due to the inflation that has occurred between 1990 and 2003 (21.2%), according to the methodology in chapter 2.6..

[29] Emission reduction potential in EU25 with the scenario 1 (2010) as baseline.

Sources of errors

Due to limited budget and very diverse measures, it has not been possible to carry out a thorough review of the MAC data in Blok et al. (2001a). The reduction potentials have been corrected according to the method described above, but still rely heavily on the Blok et al. (2001a) study. The marginal abatement costs for the measures totally rely on the Blok et al. (2001a) study even if it is possible to assume that the costs have changed and that some assumptions in Blok et al. (2001a) are questionable. However, the Blok et al. (2001a) study has been the best available source of information for MAC-data, but the study needs further updating which raises the need of a much more extensive study.

The assessments to reduce the potentials for the measures above (CF_{time}, $CF_{scenario\ 0}$, $CF_{scenario\ 1}$, and $CF_{EU\text{-}ETS}$) include assumptions that have not been possible to verify. The assessments have been done with the knowledge in the project team. However, the uncertainties are considerable. The assessments of the potentials have great impact on the aggregated MAC-curves which are important for the final results of the project. It is therefore necessary to bear in mind these uncertainties when interpreting the final results.

The $CF_{EU15\text{-}EU25}$ only relies on the emission difference between EU15 and EU25 and do not include any difference in reduction potentials between EU15 and EU10.

The $CF_{inflation}$ assumes the same price change for all components in all measures. Probably different components (as fuel cost and investment cost) of the MAC have had different price changes. This is not considered in this chapter.

The energy price used in Blok et al. (2001a) is unknown. An electricity price of 4 eurocents is mentioned in Joosen and Blok (2001). However, it is only presented as an example and it is not stated that this is the electricity price that has been used in all calculations.

Blok et al. (2001a) does not include fuel changes e. g. change from coal to natural gas or change from oil to biomass in the manufacture industry, households and services sectors in this chapter. It has unfortunately not been possible to add these measures due to lack of information about prerequisites used in Blok et al, as the comparisons would be uncertain.

(4) Summary: Cost effective emission reduction (Marginal abatement cost curve)

The MAC-curve for the manufacturing industry sector is presented in Figure 5. The large number of measures (81) makes it difficult to point out the biggest measures in the graph. The policies and measures with the biggest impact on the difference between PAM1+ and PAM1+ ETS (compatible with EU ETS) are measure number 53 “reducing nitritic acid in chemical industry”, number 63 “reduction of HFC in other industry” and number 70 “reduction of PFC in other industry”[30]. These measures affect non-CO_2 GHG and are therefore not included in PAM1+ ETS (policies and measures beyond the planned measures of scenario S1, compatible with EU ETS). The largest remaining emission reduction option is “Miscellaneous measures for the different industry sub-sectors”.

MARGINAL ABATEMENT COSTS FOR MANUFACTURING INDUSTRIES: PAM1+

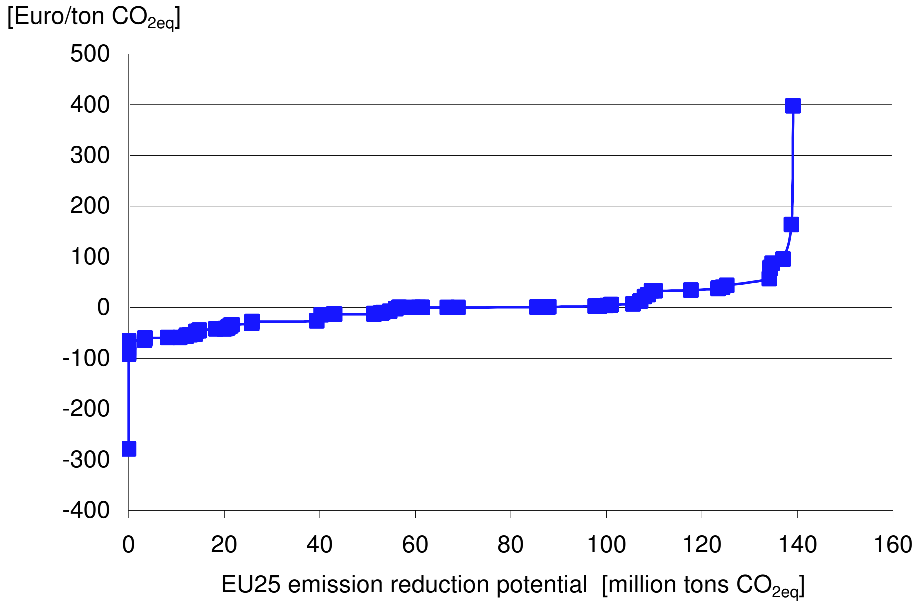


Figure 5 MAC curve for 2010 for additional policies and measures beyond the planned measures of the scenario S1 (PAM1+) for manufacturing industries for EU25.

The MAC curves for the household sector is presented in Figure 6. The largest emissions derive from measure number 8 “wall insulation”, number 9 “roof insulation” and number 13 “insulate windows”. All these measures’ reduction potentials are reduced to 50% in for PAM1+ ETS (PAM1+ compatible with EU ETS) compared to scenario 1. The reason is the assumption that 50% of the emissions from heating in households are direct and 50% are indirect emissions in energy supply companies as electricity or district heating systems.

---

[30] See annex for further information about these and all the other measures.

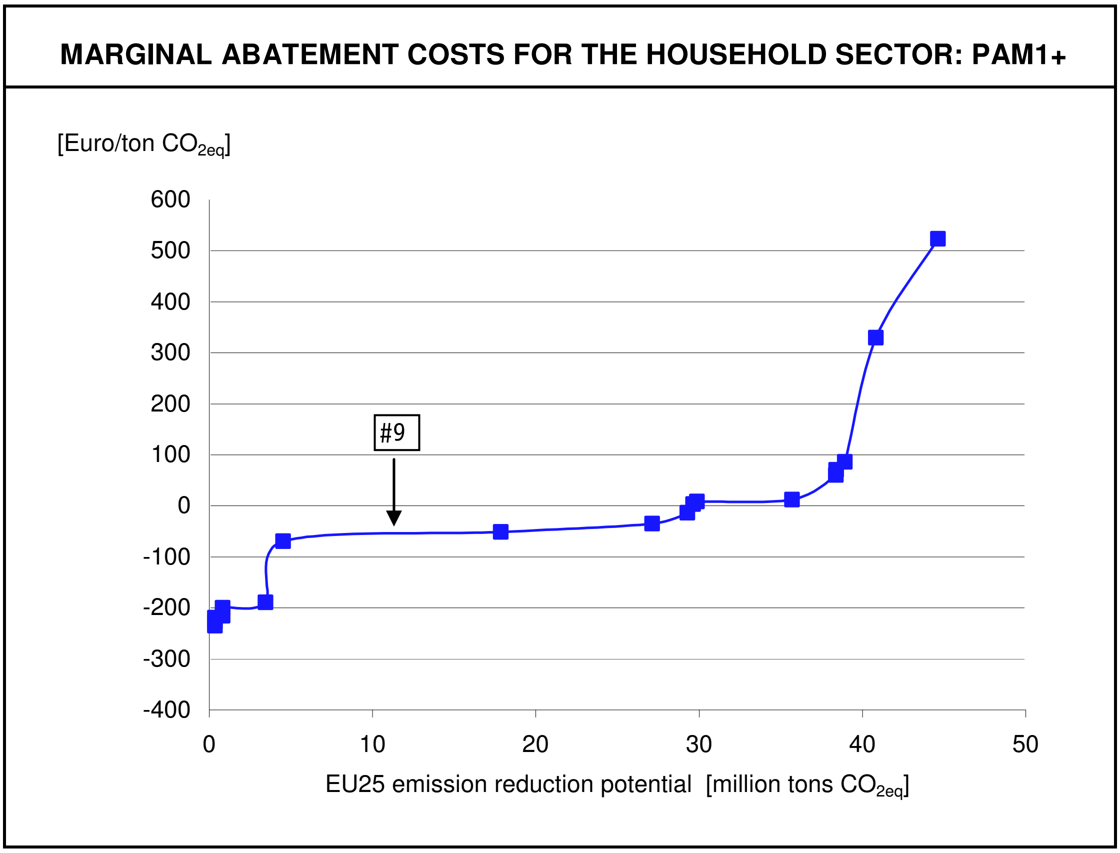

MARGINAL ABATEMENT COSTS FOR THE HOUSEHOLD SECTOR: PAM1+

Figure 6 MAC curve for 2010 for additional policies and measures beyond the planned measures of the scenario S1 (PAM1+) for the household sector for EU25.

The MAC curves for the service sector is presented in Figure 7. The largest measures in the service sector are measure number 6 “Building energy management systems” and number 9 “insulation of windows”. See the annex for more information about the measures.

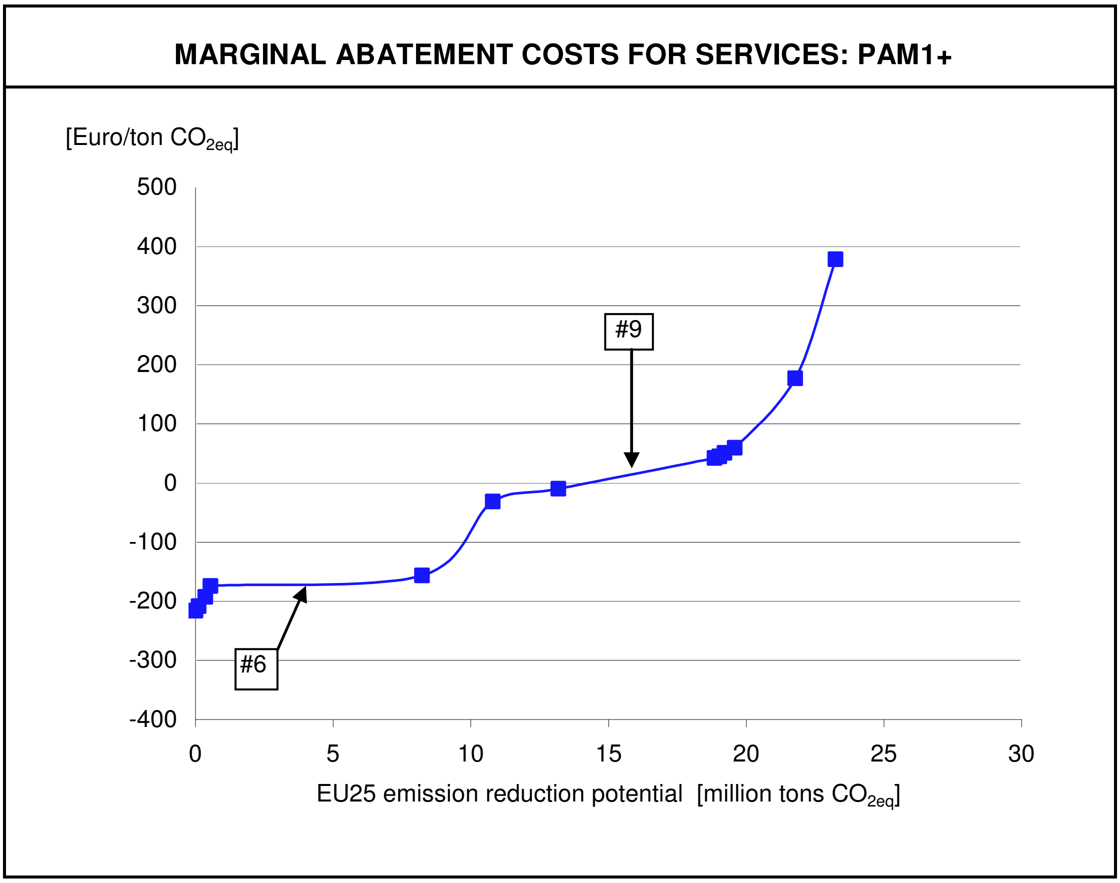


Figure 7 MAC curve for 2010 for additional policies and measures beyond the planned measures of the scenario S1 (PAM1+) for the service sector for EU25.

4.3. AGRICULTURE AND FORESTRY (INFRAS)

(1) Literature

The main literature reference used for the analyses of the agricultural sector, especially for the MAC curves has been Blok et al. (2001a) and the associated sector study by Bates (2001). Forestry which is – together with agriculture – part of this study has not been described by Blok et al. (2001a) or Bates (2001) at all. Therefore for forestry no corresponding emission reduction potentials or MAC data could be referred to from the Blok study.

Other literature sources do either not show both reliable emissions and costs figures, or the figures are not available on a disaggregated level for the EU member states or for individual measures. The most important screened literature sources are listed in the annex in a uniform reporting format.

(2) Measures

The measures described in Bates (2001) and Blok et al. (2001a) are mainly technologically driven. The described costs of those measures are viewed with a rather “narrow” and micro-economic standpoint rather than with a comprehensive standpoint, considering long-term sustainability issues well beyond the first commitment period 2008-2012:

- The estimated costs do not include leakage, produced outside of the EU.
- Negative effects on the animal well-being are accepted when suggesting some measures.
- Some cost relevant factors are neglected in the cost figures, such as how to get the farmers to accept and implement a certain technical measure, and some investments are assumed to be undertaken for other reasons than for the option described.
- It is assumed that with an increase of total CH_4 emissions per animal, methane reductions could only be obtained if overall production levels are kept constant (the number of animals will decrease even more than assumed for the baseline scenario due to increased productivity).
- None of the enteric methane reducing measures are planned and they lack of an EU policy framework to push these measures.

We consider that a **cost effective measure** should be understood cost-effective in a broader sense. Costs created by leakage in other countries or costs to recover impaired animal health should be considered in a minimum. Cost-effectiveness should therefore be seen with an overall economic view based on principles of sustainability (including the ‘social’ and ‘ecological’ part of sustainable agriculture and with a perspective passing the 2012 horizon). External costs such as leakage should be accounted globally. With this view, Kyoto target options should not only reduce GHG emissions in the short term (within the Kyoto timeframe 2008-2012) or in the EU only but the emission reductions should basically not be undone with another increase in emission after the Kyoto period or in other countries outside the EU. We consider cost effective measures to have a long-term emission reduction potential which is at least on the level of the targeted Kyoto emission reductions and which do not produce costs in other countries that equal or undo the emission reductions achievable.

Of all the measures described by Blok et al. (2001a) and Bates (2001) only the measures “proprionate precursors, dairy” (measure 9), “proprionate precursors, non-dairy” (measure 10), “manure storage: slowing down anaerobic decomposition” (measure 11) and “common agricultural policy reforms: set-asides” (measure 14) could be proposed as GHG emission reduction measures accountable or achievable for Kyoto emission reduction targets with this broader economic view of cost effectiveness (see Table 10). All the other measures are either not regarded as cost effective and sustainable (measures 1-8) for different reasons – but mostly because they produce leakage and threaten animal well-being – or are actually energy producing measures (measures 12-13) which should therefore be considered in the energy supply sector (see chapter 4.1). Table 10 shows the set of agricultural measures described by Bates (2001) and the assessment of the emission reductions and MAC data. The correction factors are applied as described earlier.

Data of original source				**Assessment**					
Name of measure (and source, incl. page)	**MAC (€/ton CO_{2eq})**	**GHG red. (Mtonnes CO_{2eq} per year)**	**Level of implementation (in % for 2010)**	**Status of implementation:** a=implemented, b=planned, c=neither a nor b	**Category 1, 1d, 2, 3, 4**	**Correction applied to the MAC (€/t CO_{2eq}) and deflation factor of 1.2 or emission potential CF (EP) and EU15 ->EU25 factor**	**MAC (€/ton CO_{2eq})**	**GHG red. (Mtonnes CO_{2eq} per year)**	**Comment (Rational of classification)**
1) EF: Replace roughage by concentrates (non-dairy) (Bates 2001:52-53)	-212	0.3297	10%	c	1d	-	-	-	Costs only considering the “narrow” micro-economic standpoint and are even then very optimistically estimated. There are some trends in the other direction (increasing use of home grown forages rather than concentrates; Bates 2001). Measures create leakage and other external costs. Lack of an EU policy framework (no political support/decision known).
2) EF: Replace roughage by concentrates (non-dairy) (Bates 2001:52-53)	-212	0.3339	10%	c	1d	-	-	-	
3) EF: Change composition of concentrates to include extra fats (dairy) (Bates 2001:52-53)	-70	0.1932	5%	c	1d	-	-	-	Costs only considering the “narrow” micro-economic standpoint and are even then very optimistically estimated. Negative effects on the animal well-being. Measures create leakage and other external costs. Lack of an EU policy framework (no political support/decision known). The viability and effectiveness of this option in actual farming situations has yet to be proven. Combination with other enteric methane reducing measures is very uncertain.
4) EF: Change composition of concentrates to include extra fats (non-dairy) (Bates 2001:52-53)	-70	0.1953	5%	c	1d	-	-	-	
5) EF: Improved level of feed intake with improved genetics (dairy) (Bates 2001:52-53)	-49	2.0706	50%	c	1d	-	-	-	Costs only considering the “narrow” micro-economic standpoint and are even then very optimistically estimated. Negative effects on the animal well-being. Lack of an EU policy frame-

Data of original source					**Assessment**					
	Name of measure (and source, incl. page)	**MAC (€/ton CO_{2eq})**	**GHG red. (Mtonnes CO_{2eq} per year)**	**Level of implementation (in % for 2010)**	**Status of implementation:** a=implemented, b=planned, c=neither a nor b	**Category 1, 1d, 2, 3, 4**	**Correction applied to the MAC (€/t CO_{2eq}) and deflation factor of 1.2 or emission potential CF (EP) and EU15 ->EU25 factor**	**MAC (€/ton CO_{2eq})**	**GHG red. (Mtonnes CO_{2eq} per year)**	**Comment (Rational of classification)**
6)	EF: Improved level of feed intake intake with improved genetics (non-dairy) (Bates 2001:52-53)	-49	2.0958	50%	c	1d	-	-	-	work (no political support/decision known).
7)	EF: Change composition of concentrates to include NSC (dairy) (Bates 2001:52-53)	-16	0.3486	5%	c	1d	-	-	-	Costs only considering the "narrow" micro-economic standpoint and are even then very optimistically estimated. Negative effects on the animal well-being. Lack of an EU policy framework (no political support/decision known). The viability and effectiveness in actual farming situations has yet to be proven. Combination with other enteric methane reducing measures is very uncertain.
8)	EF: Change composition of concentrates to include NSC (non-dairy) (Bates 2001:52-53)	-16	0.3528	5%	c	1d	-	-	-	
9)	EF: Proprionate precursors (dairy) (Bates 2001:52-53)	32	0.6636	5% (25% of cattle)	c	1	MAC: +30 deflation: 1.2 EP: 2 ->EU25: 1.31	62	0.3318	Lower level of implementation than 5% (Bates 2001) and higher costs according to own estimates. The viability and effectiveness in actual farming situations has yet to be proven. Lack of an EU policy framework (no political support/decision known) but no leakage or animal harm known.
10)	EF: Proprionate precursors (non-dairy) (Bates 2001:52-53)	67	0.4410	5%	c	1	MAC: +30 deflation: 1.2 EP: 4 ->EU25: 1.31	97	0.1103	
11)	Manure storage: Slowing down anaerobic decomposition (Bates 2001:80)	0	0.7434	?	c (?)	1	MAC: +50 deflation: 1.2 ->EU25: 1.31	50	0.7434	Zero costs as assumed applied for other reasons are not regarded as realistic.
12)	Energy production: Farm scale anaerobic digestion (Bates 2001:71-72/80)	75 (heat/cc) 31 (heat/wc) -40 (h&p/cc) 46 (h&p/wc)	5.9493	-	-	1 (1d for agric.)	-	-	-	Not part of agricultural sector (->energy supply sector). Potential assumes no interaction between options. Higher costs according to own estimates.
13)	Energy production: Centralised anaerobic digestion (Bates 2001:80)	-8 (h&p/cc) -5 (h&p/wc)	0.6951	-	-	1 (1d for agric.)	-	-	-	Not part of agricultural sector (->energy supply sector). Higher costs according to own estimates.

Data of original source				Assessment					
Name of measure (and source, incl. page)	**MAC (€/ton CO_{2eq})**	**GHG red. (Mtonnes CO_{2eq} per year)**	**Level of implementation (in % for 2010)**	**Status of implementation:** a=implemented, b=planned, c=neither a nor b	**Category 1, 1d, 2, 3, 4**	**Correction applied to the MAC (€/t CO_{2eq}) and deflation factor of 1.2 or emission potential CF (EP) and EU15 ->EU25 factor**	**MAC (€/ton CO_{2eq})**	**GHG red. (Mtonnes CO_{2eq} per year)**	**Comment (Rational of classification)**
14) CAP reforms: Set-aside (Bates 2001:28/83)	0	6.727	10% until 2006/07	a/b	2	MAC: +30 deflation: 1.2 EP: 2 (assumption: 50% of EP for planned, 50% for implemented measures) ->EU25: 1.31	30	3.3635	Zero costs assumed (implementation within the CAP reform): this does not reflect the true costs (e.g. with EU subsidies). But no better figures available. Assumption: 5% implemented (baseline scenario), 5% planned (scenario 1)
Total Agriculture		21.4						S1: 4.4 PAM1+: 1.6	Without measures 12 and 13 (to the energy supply sector)

Table 10 Summary of agricultural data to the measures described by Blok et al. (2001a) and Bates (2001) and classification of the measures for the status of implementation, the category, and the description of the reported and the "corrected" MAC and GHG reduction data according to the amendment to the methodology (INFRAS 2006b). EF=enteric fermentation; NSC=non-structural carbohydrates; CAP=common agricultural policy; cc=cooler countries, wc=warmer countries, h&p=heat and power production.
Category 1: The data reported is clearly much too optimistic. The MAC reported is increased by 30-50 €/t CO_{2eq}, or/and the GHG reduction potential is reduced with a correction factor (CF) of 2-4.
Category 1d: The measure is considered to be outright "unrealistic", theoretical only, or does not consider long-term sustainability. The measure is listed but deleted as possible Kyoto option.
Category 2: Probably too optimistic, valid but probably more expensive or less effective; the MAC reported is increased by 10-30 €/t CO_{2eq}, or/and a CF of 30-50% for the reduction volume is proposed.
Category 3: The MAC and GHG reduction data are reasonable. No CF is applied.
Category 4: From today's standpoint the data reported is too pessimistic. The MAC reported is decreased by 10-30 €/t CO_{2eq}, or/and a CF of 30-50% for the reduction volume is applied.
S1 being the scenario 1 (development with additional planned measures) and
PAM1+ being the additional policies and measures beyond the planned measures of S1).

The costs of the measures in the agricultural sector were rather underestimated in the Blok sectoral study (Bates 2001) and/or the possibility of implementation until 2010 are overestimated.

(3) Achievable emissions reductions (2010) and marginal abatement costs

Scenario S1 with one measure: According to Table 10 only one (already partly implemented) measure is regarded as planned within the above definitions (=1 measure to the scenario S1):

› **Increasing of set-asides on farmed land**: This is a measure diminishing the use of fertilizer and thus the N_2O emissions. The introduction of set-asides is one reason for the decline in fertiliser use since the early 1990s. Reductions in EU Member States are likely to vary, depending on current fertilisation rates, crop and soil type, crop productivity and climatic differences. In estimating the impact that set-asides might have on fertiliser use and N_2O emissions it is important to note that it is possible that set-asides could be used to grow non-food crops, and hence fertiliser use on set-asides would not be zero, and that it is also possible that the retention of set-asides would encourage farmers to maximise margins on cropped areas, leading to changes in crop types grown which could lead to an increase in average fertiliser use per ha in cropped areas. Bates (2001) estimated the possible impact of set-asides by assuming a reduction in nitrogenous fertiliser use on the 10% set-aside of 50 kg N/ha.

Set-asides are fostered through the European Common Agricultural Policy (CAP) reform. Bates (2001) assumes no costs for this measure. Actually, if the European agricultural subsidies for set-asides are accounted, the "true" costs of this measure would be rather high. In lack of adequate cost data, an intermediate cost assumption of 30 €/t CO_{2eq} is assumed according to the common methodological framework described in chapter 2.6 and the cost assessment given in Table 10 (measure 14). Furthermore it is assumed that half of the emission reductions estimated by Bates (2001) for 2010 is already achieved through implementation until 2004 and should therefore be regarded as part of the baseline scenario (scenario 0). Within the assessment of the MAC also a deflation factor of 1.2 and for the assessment of the emission reduction potential the enlargement of the EU15 figures (Bates 2001) to the EU25 is considered with a correction factor of 1.31 for the agricultural sector (see Table 10). The emission reduction potential of this planned measure is estimated to be about 4.4 Mtonnes CO_{2eq} accountable to the scenario 1.

PAM1+ with three measures: Three measures described by Blok et al. (2001a) and Bates (2001) are considered as PAM1+ (additional policies and measures beyond the planned measures of S1):

› **Manure storage: slowing down anaerobic decomposition of manure in stables:** Systems with a slatted floor are very common in intensive pig farming operations and manure is often stored there for some months (Bates 2001, p. 61/62). This creates relatively high emissions, as the manure begins to anaerobically decompose, particularly as the housing is often heated, especially in cooler countries of the EU. Emissions can be reduced by moving the slurry to an outdoor storage system. For example, it has been found that at a temperature of 10°C emissions from slurry can be 60 to 100% lower than emissions from slurry stored in animal housing kept at 20°C (Zeeman 1994, in Bates 2001, p. 62). Manure can be regularly moved to an outdoor storage system using a manure slide. Ensuring that the manure pit or stable is completely cleared out can also help to reduce methane emissions. In general 10-15% of slurry remains in the manure storage after emptying, and this manure acts as an inoculant, so that anaerobic decomposition of fresh manure added to the system begins quickly. Experimental work has shown that when inoculant was not present methane production had not begun within 60 days (Zeeman 1991, in Bates 2001). Ensuring that all manure is removed from the cellar can be done by rinsing out the manure cellar or stable floor. As long as this is done using cleansed water separated from the collected slurry, the volume and dry matter content of the manure is not increased so that storage facilities for the slurry do not need to be increased (Bates 2001, p. 62). Bates (2001) estimated that this option might lead to a 10% reduction in emissions from intensive pig rearing systems, where pigs are housed indoors in stables with slatted floors and manure is currently stored for long periods (i.e. greater than a month; Bates 2001, p. 63). In some countries such as the Netherlands, systems to move slurries to out-door stores and to completely empty slurry pits are currently being installed to help reduce ammonia emissions. It is assumed that this option is applied only in countries with a cooler climate (all EU countries except Greece, Italy, Portugal and Spain), and only to larger herds and it is also considered applicable only where manures are currently stored in pits for greater than 1 month. From IPCC guidelines (1997), 73% of pig slurry in Europe is stored in this way (Bates 2001, p. 62).

› **Enteric fermentation: propionate precursors – dairy:** By increasing the presence of propionate precursors such as the organic acids, malate or fumarate, more of the hydrogen in the rumen is used to produce propionate, and methane production is reduced. Propionate precursors can be introduced as a feed additive for livestock receiving concentrates. The propionate precursor, malate, also occurs naturally in grasses, and it is possible that plant breeding techniques could be used to produce forage plants with high enough concentrations of malate. Considerable research is needed, but if these techniques were successful then this mitigation option could then also be used with extensively grazed animals (Bates 2001, p. 46). It is estimated that if successful, the option could reduce methane emissions by up to 25%, (ADAS 1998, in Bates 2001), and that there could be other benefits to the livestock industry such as improved feed degradation which would be likely to reduce feed costs. Another possible benefit would be a reduced incidence of acidosis (a digestive disorder) in high producing dairy cows and intensively reared cattle, which could lead to considerable cost savings. As propionate precursors naturally occur in the rumen, they are likely to be more readily acceptable than antibiotics or chemical additives. Propionate precursors would be given to animals as daily supplements. Supplements are given to dairy cows year-round, but non dairy cattle can only be fed with supplements when they are housed inside which is assumed on average to be 40% of the year.

› **Enteric fermentation: proprionate precursors - non dairy:** see description above.

More agricultural measures are described in Bates (2001) but could not be quantified on an EU-wide level because the quantitative data depend on local parameters (such as type of cropland or management practices), political framework conditions, unknown level of implementation and others. Additionally, there are many other possible GHG reduction measures for the agricultural sector which are not mentioned in the reference studies Blok et al. (2001a) or Bates (2001). Unfortunately, accurate emission potential and cost data could be found for neither the EU15 nor the EU23/25. But we think that the overall contribution of these measures would not be very high compared to PAMs of other sectors.

For all the **carbon sink measures** on cropland it must be seen that they have a limited sequestration potential because they are only temporary measures. The sequestration potential is characterised with a saturation of the carbon content in the soil. Also, the carbon sinks are potential carbon sources, when the captured carbon in the soil could again be released in case of land use or management changes. If a farmer comes back to tillage after a period of carbon sequestration with no tillage the captured carbon might be released at once (Hediger et al. 2004). It is important for accounting the GHG to keep this carbon captured in the soil. This implies no change in agricultural land use or management practises after the reach of the maximum carbon stock. In case of carbon sequestration on agricultural soils changes of CH_4 and N_2O emissions also have to be considered.

Afforestation (under Article 3.3 of the Kyoto Protocol) often results not as consequence of a measure planned but as an uncontrolled gain of forest starting with i.e. in-growth of bushes on previously farmed land. This in-growth of non-forest land since 1990 can be attributed to the Kyoto target if bushes/trees could be considered as forest (with a height of at least 3 m). Nevertheless within our study afforestation and reforestation should be regarded for in the baseline scenario. For planned afforestation with tree planting activities (which could actually be referred to as additional and for which costs could be calculated with the availability of MAC) it is now too late to be considered for the Kyoto period (2008-2010) since these afforestation activities would not lead to forests in the Kyoto timeframe (with trees over 3 m) or could only provide a small accountable reduction potential. This means that afforestation/reforestation is either part of the baseline scenario or could be neglected if no emission reductions within the Kyoto timeframe are expected. Therefore abatement costs or even MAC curves for afforestation/reforestation/deforestation activities being accountable for the Kyoto target and not being part of the baseline scenario must not be calculated in our study as additional measures.

According to EEA (2005, p. 43) only Portugal and Slovenia have already decided to account for **forest management** (under Article 3.4 of the Kyoto Protocol) leading to an estimated additional carbon sequestration of 0.8 and 1.3 Mtonnes CO_2 per year. Unfortunately no cost estimates for forestry sink activities could be found for the EU. Kauppi et al. (2001) state that mitigation costs of forestry can be as low as about 20-100 USD/t C in developed countries (4.5-22.5 €/t CO_2). But this estimate is very vague.

The European climate change programme estimates that potentially 93-103 Mtonnes CO_2 could be sequestered through the enhancement of sink activities in the agricultural and forestry sectors (EEA 2005a, p. 43). The carbon sequestration potential of afforestation and reforestation measures, forest management and natural forest expansion in the EU15 Member States is estimated 33 Mtonnes CO_2 until 2010 if the measures are fully implemented, compared to business as usual (EU 2006, p. 19).

Summary of all measures in the agriculture and forestry sector: The table below lists all measures quantified by Blok et al. (2001a) and Bates (2001) for the agricultural sector (indicated with a "+" in the column "cons. Blok"). These measures are supplemented with other possible abatement measures for the agricultural sector described in different literature and also with policies and measures in the forestry sector which was not considered at all in the Blok study (Blok et al. 2001a). All the measures which the authors consider as potentially relevant or which should be considered in this study whenever quantitative data were available are marked with a "+" in the column "Pot. this study" (should potentially be considered in this study if data were available). Unfortunately for most of these options no quantitative data (i.e. emission reduction potential and marginal abatement costs) could be found within the literature search for the EU15 or the EU25. All the measures which should potentially be regarded as GHG reduction options within the Kyoto protocol AND for which quantitative cost data for at least the EU15 could effectively have been found are indicated with a "+" in the column "Eff. this study" (effectively considered in this study) in the table below.

The PAMs could be aggregated in the following groups of measures (see annex to chapter 4.3 for detailed descriptions of the measures):

- **Agriculture**
    - **Enteric fermentation:** 10 measures, all of them described by Blok et al. (2001a) and Bates (2001).
    - **Animal husbandry and manure management**
    - **Energy production (biofuels and electricity production):** these measures are described by Blok et al. (2001a) in the agricultural sector but belong to the energy supply sector according to this study.

  - **Cropland management, agricultural soils:** This is a broad group with many PAMs.
  - **Reduction of use of fossil fuels:** these are energy efficiency measures in agriculture disregarded by Blok et al. (2001a) for the agricultural sector.
  - **Behavioural change on demand side:** This would actually be the most decisive PAM of the agricultural sector according to own estimates. Unfortunately no targets or costs figures are available.
- **Forestry**
  - **Afforestation/reforestation/deforestation:** These measures relate to Article 3.3. of the Kyoto protocol.
  - **Forest management:** These measures relate to Article 3.4. of the Kyoto protocol.

AGRICULTURE & FORESTRY: POTENTIAL GHG EMISSION REDUCTION MEASURES						
Potential GHG emission reduction measures	**CO_2**	**CH_4**	**N_2O**	**Cons. Blok**	**Pot. this study**	**Eff. this study**
Agriculture						
Enteric fermentation						
› Replace roughage by concentrates, dairy		x		+	-	-
› Replace roughage by concentrates, non-dairy		x		+	-	-
› Change composition concentrates by extra fat, dairy		x		+	-	-
› Change composition concentrates by extra fat, non-dairy		x		+	-	-
› Change composition concentrates by non structural carbohydrates, dairy		x		+	-	-
› Change composition concentrates by non structural carbohydrates, non-dairy		x		+	-	-
› Improved level feed intake, dairy		x		+	-	-
› Improved level feed intake, non-dairy		x		+	-	-
› Propionate precursors, dairy		x		+	+	+
› Propionate precursors, non-dairy		x		+	+	+
Animal husbandry and manure management						
› Animal husbandry: Reduction of grazing, increase in indoor animal husbandry			x	-	+	-
› Manure storage: Slowing down anaerobic decomposition of manure in stables		x	(x)	+	+	+
› Reduction of ammonia emissions (indirect emissions atmospheric deposition)						-
Energy production (biofuels)						
› Controlled anaerobic digestion: farm-scale	(x)	x	(x)	+	-	-
› Controlled anaerobic digestion: centralised	(x)	x	(x)	+	-	-
› Bioenergy from lingo-celluloid wastes	(x)	x	(x)	-	-	-
› Bioenergy crop production	x	x	(x)	-	-	-

AGRICULTURE & FORESTRY: POTENTIAL GHG EMISSION REDUCTION MEASURES						
Potential GHG emission reduction measures	**CO_2**	**CH_4**	**N_2O**	**Cons. Blok**	**Pot. this study**	**Eff. this study**
Cropland management, agricultural soils						
› Rice production: Reduction of multiple-aerated intermittently flooded rice cultivation (irrigation)	(x)	x	(x)	-	+	-
› Manure application: near-soil placing of liquid manure		x	x	-	+	-
› Fertiliser Management: Reduction of use of (synthetic) fertiliser, increase N-efficiency, demand management, reduction of nitrogen leaching and run-off (CAP reform)	(x)		x	(+)	+	-
› Fertiliser free zones (avoiding fertiliser loss, CAP reform)			x	(+)	+	-
› Precision farming	x		x	(+)	+	-
› Tillage intensity reduction, no tillage (direct cropping)	x		x	-	+	-
› Crop rotation, crop mix alteration (with N fixing crops), increase of winter cover crops and perennials.	x		(x)	-	+	-
› Set-asides: Transformation of arable land in continuous grassland, extensivation of farm land (CAP reform)	x			+	+	+
› Field burning of agricultural residues (avoidance)	x	(x)		-	+	-
› Renaturation of organic soils	x			-	+	-
Reduction of use of fossil fuels						
› Energy-efficient building design	x			-	+	-
› Energy efficiency (fuel, heat and power) in farm-based processes (i.e. horticultures, technical hay ventilation, crop drying processes)	x			-	+	-
Behavioural change on demand side						
› Reduction of milk and meat consumption	x	x	x	-	+	-
Forestry						
Afforestation/reforestation/deforestation (Art. 3.3. of Kyoto protocol)						
› Afforestation or reforestation: Carbon sequestration	x			-	+	(+)
› Deforestation	x			-	+	(+)
Forest management (Art. 3.4. of Kyoto protocol)						
› Reduced impact logging	x			-	+	-
› Enrichment planting on logged-over forest or secondary growth forest	x			-	+	-
› Sustainable forest management (other measures)	x			-	+	-

Table 11 Summary of potential measures in the agricultural and forestry sector.
"Cons. Blok": + means that this measure is considered as an emission reduction measure in Blok et al. (2001a) and Bates (2001), (+) means that the measure is only described qualitatively in Bates (2001).
"Pot. this study": + means that this measure is considered as a potential emission reduction measure for GHG abating in our sectoral study.
"Eff. this study": + means that this measure could effectively be considered as an emission reduction measure for GHG abating in our sectoral study with emission and cost data available to calculate marginal abatement costs for the EU15 or EU23/25.

(4) Summary: Cost effective emissions reduction within the sector (Marginal abatement cost curve)

The emission reduction potential of the above described three additional policies and measures (PAM1+ beyond the planned measures of S1) for the EU25 is estimated to 1.6 Mtonnes CO_{2eq} only. Figure 8 shows the summarised MAC curve for the three remaining PAM1+ according to the own classification (see Table 10 for details of the assessment).

MARGINAL ABATEMENT COSTS FOR AGRICULTURE: PAM1+

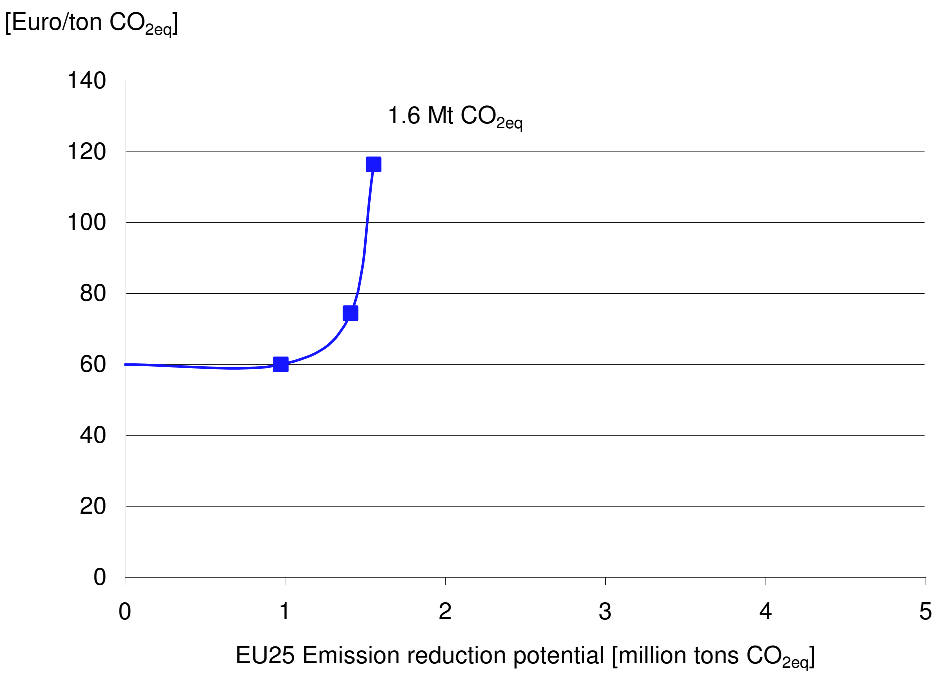


Figure 8 MAC curve of the three policies and measures (PAM1+) from the Blok study (Bates 2001) which are considered as possible additional PAMs beyond the planned measures of scenario S1.

In comparison with the overall GHG emissions and reduction potential of other sectors, the additional planned and not yet planned measures of the agricultural and forestry sector have only a minor contribution to the Kyoto target. Whereas agricultural and forestry emissions are important within the baseline scenario in the overall accounting to achieve the Kyoto target.

4.4. WASTE (IFEU)

(1) Literature

The bottom up study by Bates and Haworth (2001) is used as the lead study for the waste sector (the sector study to Blok et al. 2001a). There are some problems based on the methodology and documentation in Bates and Haworth (2001) which make a detailed quantitative answer on the listed issues difficult. Similar to the energy sector in Blok et al. (2001a) there are no activities given for individual measures and baseline technologies for the base years 1990/95 and the target year 2010 (with some exceptions in the text), only emission data are listed.

Bates and Haworth (2001) are correctly stating that in the waste sector there is a lot of uncertainty concerning actual mechanisms. The estimates can be judged to be given profound and well-knowing. But even then ranges and sensitivities are very large. Most data are relying on single plant information.

(2) Measures

For the waste sector the following categories of measures/processes and pollutants are considered in Bates and Haworth (2001):

- Waste diversion options away from landfills to a alternative treatments (methane, CO_2 mostly negligible) – 5 measures
- Collection and utilization of landfill gas (methane, CO_2 mostly negligible) – 3 (4) measures
- Improved Oxidation through improved landfill capping (methane) – 1 measure.

For the update no additional measures are considered but these 10. There might be a couple of further policies and measures in discussion like gasification, pyrolysis (both alternatives to incineration), further specific concepts of MBT (like dry stabilisation) or RFD (refuse derived fuel) concepts. But fundamental studies to compare these options in an equivalent way to the measures discussed by Bates and Haworth (2001) are not available; resp. an intensive study to extract data from the number studies touching that fields wouldn't be feasible within this project. On the other hand we wouldn't estimate these alternative options to deliver results in a different order of magnitude. The measures are discussed below.

(3) Achievable emissions reductions (2010) and marginal abatement costs

In the following the measures and data according to Bates and Haworth (2001) are discussed. In the next section the adaptation to the EU25 and the smaller time range (2006 to 2010 instead of 2000 to 2010) as well as different assessments of potentials are presented.

Waste diversion options away from landfills to a alternative treatments (methane, CO_2 mostly negligible) – 5 measures

The reduction potential of the alternative treatment options is describing a range from quite high to relatively small according to the type of option following Bates and Haworth (2001). Compared to the two further categories these measures lead to relatively high costs because of necessary investments to move away from “cheap” landfilling.

For this (sub-)sector 5 categories of measures are considered:

› **Composting:** This measure comprises a separate collection of biodegradable waste, treating it aerobically and applying the processed compost in agri/horticulture. This measure bears a relatively low potential due to the acquirable mass of organic matter. The reduction potential has been estimated 1 to 2 Mtonnes CO_{2eq}/a depending on the efficiency of landfill gas collection in the substituted case. The average abatement costs for 1 t of CO_{2eq} are ranging from 60 to 76 Euro.

› **Anaerobic digestion:** This measure differs from composting in terms of biogas processing and use. Theoretically the GHG reduction potential is slightly higher to composting because energy biogas use does not provide that high share to the option’s total reduction potential. On the other hand investments are higher. The average abatement costs for 1 t of CO_{2eq} are ranging from 18 to 113 Euro.

› **MBT:** This option means an aerobic degrading of the whole waste stream and landfilling of the solid residue. With respect to the high uncertainties concerning the biological stability of the treated organic matter a rather high GHG reduction potential is figured out (2 Mtonnes CO_{2eq}/a). The average abatement costs for 1 t of CO_{2eq} are about 95 Euro according to Bates and Haworth (2001).

› **Incineration:** This is the most effective measure to reduce GHG emission because incineration is combined with energy use of the total calorific value of waste. The actual efficiency is therefore highly sensitive. The potential is ranging between 11 and 23 Mtonnes CO_{2eq}/a. Also the range of abatement costs is large with numbers between 35 and 120 Euro/t CO_{2eq}.

› **Paper recycling:** Because of high state of implementation of this measure the potential is low. On the other hand abatement costs are highly beneficial because of high prices of this secondary resource.

The data accoding to Bates and Haworth (2001) are listed in the tables below together with the updated potentials and costs (section 4: waste summary).

Landfill gas recovery and utilization – 4(5) measures

- **Flaring:** This is a very effective measure because it is easy to implement and is preventing a large amount of GHG emissions of landfills. The potential of 7 Mtonnes CO_{2eq}/a. according to Bates and Haworth (2001) is very sensitive in terms of actual state of implementation which might be higher than estimated.
- **Electricity and/or production:** Taking a minimum of capacity and the necessity of neighbouring users into account the potential is figured out smaller than flaring. But because of additional financial benefits from selling gas and/or electricity abatement costs are significantly advantageous: -2 to -19 Euro/t CO_{2eq}.
- **Upgrading to natural gas:** Only a small potential is estimated because of the necessity of specific conditions at the landfill site

Improved capping (methane)

This measure is next to incineration the most effective one. About 11 Mtonnes CO_{2eq}/a. can be avoided according to Bates and Haworth (2001). The abatement cost are estimated to be about 6 Euro/t CO_{2eq}.

As discussed above it is not possible in the scope of the project to generate consistent mass flow balances and forecasts. Instead of this assessments of updated potentials and costs (including inflation) are done as follows:

- Adaptation of specific abatement costs according to Bates and Haworth (2001) based on estimation; accompanied by a classification developed by INFRAS.
- Multiplying with an inflation factor
- Adaptation to EU25 by multiplying with factors developed by IVL
- Adaptation to the reduced implementation period compared to Bates and Haworth (2001) (2006 to 2010 instead of 2000 to 2010)
- Individual adaptation of potentials Bates and Haworth (2001)which seems to be too high or too low

The literature evaluation and adaptation work is focused on measures with high potentials. The updated potentials and costs are listed together with the data according to Bates and Haworth (2001) in the tables below (section 4: waste summary).

Comments on the MACs of incineration

Specific abatement costs

There are no sound data to recalculate the values from Bates and Haworth (2001) in an exact way. The basic study is dated 2001 and assessing data from the 90ies. Taking into account that the market in waste management activities is extremely sensitive and volatile some modification should be inevitable. From experiences e.g. in Germany a tendency of price reduction concerning the installation of incinerator plant is noticeable. Furthermore standards of energy efficiency and material recovery (ash, metals) are increasing considering requests of the new draft of the waste framework directive and increasing revenues for energy and secondary metals. Therefore a modest factor to decrease the abatement cost is assumed (0.8).

Potentials

Following the arguments from above also potentials should to be slightly corrected. An upscaling by 1.2 to 1.5 can be justified from the technical point of view. On the other hand following aspects are definitively decreasing the potential concerning the time period from 2006 to 2010. In states like e.g. Germany the implementation is completed. States with low implementation rate until 2000 probably won't be able to complete this until 2010 because of public reluctance towards incineration. Only one fourth of the potential is estimated to be realized within this period.

Comments on the MACs of MBT

Specific abatement costs

MBT is a very innovative technique. Only a few plants are operating yet. Modern plants are expected to grant high emission standards at least as efficient as MSWI. From current experiences is has to be stated that further investments might be necessary. Vice verse to MSWI a tendency of price increase concerning the installation of MBT is noticeable.

Therefore a modest factor to increase the abatement cost is estimated by us (1.1).

Potentials

Some Member states won't tap the full potential because they decided to concentrate on incineration. So only three fourth of the potential is estimated to be realized within this period.

Comments on the MACs of composting

Specific abatement costs

The separate collection of organic household waste is mostly connected with a slight increase of the number of vehicles. Also technical standards to prevent odorous emissions have increased during the last years. Taking these two aspects into account a modest factor to increase the abatement cost is estimated by us (1.2).

Potentials

Composting is widely implemented in some MS and complicated to implement fast in most other MS. So only half of the potential is estimated to be realized within this period.

All the modifications are very rough estimates. The data should be used only in the ongoing project. For all measures the adaptations for EU25 and the considered time period are applied.

(4) Summary: Cost effective emissions reduction within the sector (Marginal abatement cost curve)

The data according to Bates and Haworth (2001) and the updated potentials and costs are listed together in the tables and presented in the MAC graphs below. Table 12 summarises the most important or largest individual modifications. Considering the updated data incineration and MBT cause more than half of the overall costs.

Measure	**MAC**		**Potentials**		**Overall costs**			
	Orig.	**Assess.**	**Orig.**	**Assess.**	**Orig.**	**Assess.**	**Orig.**	**Assess.**
	Euro/t CO_{2eq}		**Mtonnes CO_{2eq}**		**M Euro**		Shares of overall costs	
Incineration (low cost)	35	32	23	3.5	808	110	27%	16%
Incineration (high cost)	120	96	10	1.9	1200	181	40%	27%
MBT	96	105	7	2.6	670	279	22%	41%
Other	11.5	9.2	30	13.6	344	107	11%	16%
Total			70	21.6	3.023	677	100%	100%

Table 12 Important individual contributions on potentials and/or costs.

No.	Measure	Bates and Haworth (2001)		Assessment				
		MAC	GHG Red.	Cate-gory	CF	MAC	GHG Red.	Comment
		€/t CO_{2eq}	Mtonnes CO_{2eq}			€/t CO_{2eq}	Mtonnes CO_{2eq}	
1	Paper recycling	-42.4	1	(3)	1	-42.4	0.5	assumptions of Bates unobjectionable
2	Heat production from landfill gas	-19.4	1	(4)	0.8	-15.5	0.5	probably the current trend of increasing electricity prices is not in considerance
3	Electricity generation from landfill gas	-2.4	5	(4)	0.8	-1.9	2.5	
4	Upgrading landfill gas to SNG	0.0	0	(4)	0.8	0.0	0.0	
5	Flaring	1.2	6	(3)	1	1.2	3.0	assumptions of Bates unobjectionable
6	Increased oxidation	6.1	11	(3)	1	6.1	5.5	
7	Anaerobic digestion	18.2	2	(2)	1.2	21.8	0.5	see text “composting”
8	Incineration (1)	35.1	23	(4)	0.9	31.6	3.5	see text
9	Composting (1)	59.4	2	(2)	1.2	71.3	0.5	see text
10	Composting (2)	76.4	1	(2)	1.2	91.6	0.3	see text
11	mechanical-biological treatment (MBT)	95.7	7	(2)	1.1	105.3	2.6	see text
12	Anaerobic digestion (2)	112.7	1	(2)	1.2	135.3	0.3	see text “composting”
13	Incineration (2)	120.0	10	(4)	0.8	96.0	1.9	see text (in curve 2 positions lower)
	Total emission reduction potential		**70**				**21.6**	

Table 13 Waste: emission reduction potentials and costs of measures according to Bates and Haworth (2001) and this study (details see text) Original source: Bates and Haworth (2001).

MARGINAL ABATEMENT COSTS FOR WASTE: PAM1+

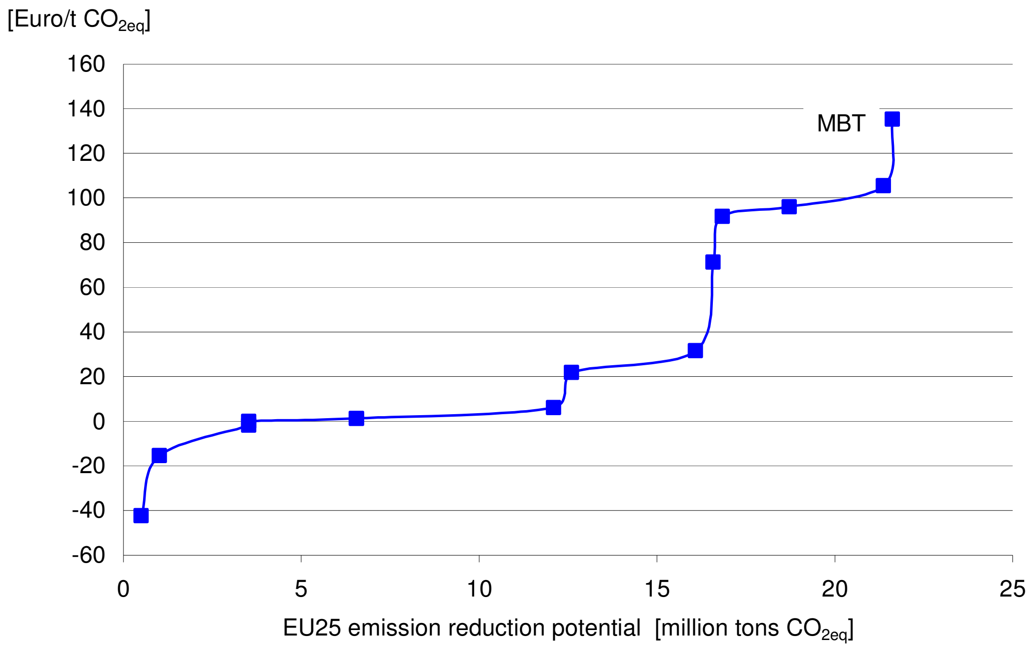


Figure 9 MAC curve for policies and measures additional to the planned measures of scenario S1 (PAM1+) of the waste sector for EU25. For details see text and Table 13 which can be used as a legend for the figure.

4.5. NON ROAD TRANSPORT (IFEU)

Relevance of non-road transport

The term Non-Road Transport covers the transport modes railways, navigation and aviation of which especially aviation contributes significantly to the total transport emissions. International maritime transport and international aviation emissions, however, are not targeted by the Kyoto protocol which is the focus of this study, though these emissions "… have increased substantially between 1990 and 2003" (EEA 2005a). Therefore non-road transport as addressed under the Kyoto protocol accounts for only a small share of total baseline transport emissions in 2010 (about 8%). The share of non-road emissions on total EU15 emissions under the Kyoto protocol is thus only in the range of 2%.

Nevertheless, especially international aviation emissions are expected to contribute significantly to global warming (EEA 2005a). Article 2 of the Kyoto protocol therefore states that the countries which sign the protocol should reduce these emissions by putting forward appropriate measures at the responsible UN organisations, the International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO).

Data availability

The sector analysis of transport in the lead study Blok et al. (2001a) only considers options for reducing greenhouse gas emissions from road transport (passenger cars and freight vehicles). A consistent and comparable set of reduction potentials and cost data for measures to reduce greenhouse gas emissions from non-road transport is thus not available in Blok et al. (2001a) and has also not been found in the considered literature.

Nevertheless, potential measures for the reduction of greenhouse gas emissions will be described in this section with a focus on aviation which is responsible for a large and increasing share of greenhouse gas emissions. Though there are some cost effective measures available in aviation, it has to be noted that these measures and their reduction potentials and costs do not distinguish between national and international aviation emissions. The derivation of avoidance costs (MAC curves) with respect to EU emissions under the Kyoto protocol is thus not possible. Though also NO_x emissions from aviation contribute to the greenhouse effect via ozone formation, these are not considered here because they are also not covered by the Kyoto protocol.

Measures in aviation

Technical measures at aircraft and optimisation of aircraft operation can be distinguished (see Cames et al. 2004, CE 2002). Technical measures can be either in short-term applied to existing aircraft or long-term introduced to new aircraft. In the latter case, accompanying measures for an accelerated fleet renewal will lead to a faster introduction of new technology. Operational measures can be further distinguished into measures at aircraft level and measures at network level.

Operational measures at aircraft level

Route optimisations at individual flight level, including a reduction of the cruising altitude, have a considerable potential to reduce climate effects of aviation. This effect varies by season and flight distance and is generally considered to be more effective for (international) long-distance flights. The introduction of new communication, navigation and monitoring systems, for instance, would allow to optimise flight routes for altitude and speed and thus also reduce delays in airspace. Fuel savings in aviation until 2010 could be up to 9.5% (Cames et al. 2004).
An estimate of specific avoidance costs for the reduction of climate effects such as contrails and cirrus clouds has also been undertaken by Cames et al. (2004). Avoidance costs per tonne of CO_{2eq} for a flight between Frankfurt and Los Angeles are about 0.23 USD if contrails and cirrus clouds are taken into account and about 2.77 USD if only contrails are considered. Avoidance costs increase considerable if the cruising altitude has to be reduced more than the assumed 1830 m.

Overall, flight route optimisations appear to be very cost effective measures for reducing climate effects of aviation, but rather apply to international long-distance flights. Such measures will therefore be less appropriate to reduce national aviation emissions which are currently covered by the Kyoto commitment. Furthermore, such measures are limited due to international airspace regulations.

Operational measures at network level

Different operational measures in aviation at network level has been assessed by Cames et al. (2004). Accordingly, flight management measures which target for a reduction of the take-off weight (e.g. by reducing the crew), an optimisation of refuelling or a reduction of empty flights can lead to further fuel savings in the range of up to 5%. Also an increase in the load factor can lead to a reduction of emissions if other flights thereby become unnecessary.

Technical measures

Aircraft turbines can be improved in efficiency by technical measures which thus lead to carbon dioxide savings. Such measures, however, are often associated with an increase in NO_x emissions which also contribute to the greenhouse effect. Since fuel consumption is a considerable cost factor in aviation, most effort has so far been put into the reduction of carbon dioxide emissions from aircraft turbines. The replacement of old turbines with new ones (re-engining) would lead to a reasonably fast introduction of new technology. It is estimated that on average about 0.5% of the annual carbon dioxide emissions can be saved for every year that the old engine has been in operation (Cames et al. 2004). In a 20 year old aircraft, carbon dioxide savings would thus be in the range of 10%.

Aircraft aerodynamics can be improved by winglets and riblets. Winglets are added to the wingtips and are mostly feasible for old aircraft, because wings of new aircraft are mostly further optimised for aerodynamics. Riblets are small grooves which are applied to the surface of the aircraft and thus reduce aerodynamic drag. For both options, carbon dioxide savings increase with the flight distance, so that they are more feasible in international long distance aviation. The estimated relative carbon dioxide reduction potential ranges between 2% and 4% for winglets and between 0.5% and 2% for riblets depending on the flight distance (CE 2002, Cames et al. 2004).

Measure	Relative reduction potential	Absolute reduction potential
Route optimisation	Up to 9.5%	30 - 130 Mtonnes CO_{2eq}
Flight management	Up to 5%	30 - 50 Mtonnes CO_{2eq}
Re-engining	0.5% per year of old engine	
Winglets	2-4%	Max. 10 Mtonnes CO_{2eq}
Riblets	0.5%-2%	

Table 14 Reduction options and potentials in international aviation. Sources: Cames et al. (2004), CE (2002).

4.6. SUMMARY AND CONCLUSIONS

In all the sectors revised and commented in chapter 4 the Blok study (Blok et al. 2001a) and its sectoral studies are confirmed as lead study. Almost all of the additional policies and measures beyond the measures of scenario S1 (PAM1+) described in this chapter are measures already described by Blok et al. (2001a). Therefore the Blok study is also the main basis for quantifying GHG emission reduction potentials and/or cost data (MACs). Nevertheless the overall reduction potential vary a lot between the estimations by Blok et al. (2001a) and our own estimations in this study. Even though the updated figures consider the EU25 (and not EU15 as shown by Blok et al. 2001a) the overall reduction potential is much smaller in this study. One reason is the adaptation of the baseline and therefore the emission potential to the new timeframe: Due to the short time frame left from 2004 to 2010 (and not 2000 to 2010 as considered by Blok et al. 2001a) the remaining emission potential of the PAMs drastically fell to a lower level. But also some estimates by Blok et al. (2001a) have to be adapted more or less drastically because of the availability of newer literature sources or the deviation of our own expert judgement for possible emissions potentials and sensible MACs.

Of all the sectors described (road transportation excepted) the energy supply sector and manufacturing industries sector show the largest reduction potentials of PAMs (PAM1+) by low marginal abatement costs (below or only little above 0 Euro/t CO_{2eq}). Also the household and non-road transportation could considerably contribute to the Kyoto target, whereas the possible contributions of the waste and service sectors are lower and the quantified contributions of the agricultural and forestry sector almost negligible.

5. SPECIAL FOCUS ON ROAD TRANSPORT

5.1. PASSENGER CARS AND VANS (TNO/CE)

5.1.1. INTRODUCTION

In support of the Impact Assessment, to be performed by the European Commission in preparation of a new strategy aimed at reducing the CO2-emissions of light-duty vehicles to a level of 120 g/km in 2012, two studies have been carried out:

The first project is Task A *"Review and analysis of the reduction potential and costs of technological and other measures to reduce CO2-emissions from passenger cars"* (contract nr. SI2.408212), which has been carried out by TNO, IEEP and LAT on behalf of the European Commission (DG-ENTR). Results are reported in (TNO 2006). This study is the source of the data on passenger cars and vans as used in this report and will be explained in more detail in the next sections.

The second project, Task B, is called *"Service contract in support of the extended impact assessment of various policy scenarios to reduce to reduce CO2 emissions from passenger cars"*, and has been carried out by ZEW and B&D Forecast on behalf of DG-ENV (contract no. 070501/2004/392571/MAR/C1). This project has assessed the macro-economic impacts as well as the impacts on the automotive industry of scenarios consisting of various technical and non-technical measures which have been reviewed in Task A. Results of Task B are reported in (ZEW 2006).

Chapter 5.1.12 makes a comparison of the two studies (Task A and Task B) and discusses the implications for the comparison of cost-effectiveness of greenhouse gas reductions in various sectors in this study.

In TNO (2006) the following technical and non-technical CO_2 reduction options for passenger cars (M_1-vehicles) and light-duty commercial vehicles (N_1-vehicles) have been reviewed with respect to costs and CO_2 reduction potentials:

- technical options to reduce fuel consumption at the vehicle level
- application of fuel efficient air conditioning systems
- options to reduce vehicle and engine resistance factors
    - low rolling resistance tyres (retrofit)
    - tyre pressure monitoring systems (new vehicles)
    - low viscosity lubricants (retrofit)
- application of CNG
- increased application of biofuels
- fuel efficient driving
- technical options to reduce fuel consumption of N_1 vehicles

In this chapter the results of TNO (2006) are briefly summarized and translated to meet the input requirements set by the methodology developed for this study. First some general methodological issues will be discussed, after which all options will be described one-by-one. For details on the assessment of various options the reader is referred to TNO (2006).

5.1.2. METHODOLOGICAL ASPECTS

Calculation of CO_2 abatement costs

In TNO (2006) various technical and non-technical options for reducing the CO_2 emissions of passenger cars and vans are compared on the basis of CO_2 abatement costs, i.e. the net costs to society per unit of CO_2 avoided. For this purpose the following formula is used:

$$\text{CO}_2 \text{ abatement costs } = \frac{\text{investment} - \text{NPV (lifetime fuel cost savings)}}{\text{lifetime CO}_2 \text{ reduction}} \qquad (5.1)$$

The net costs equal the investment costs (retail price excl. tax) minus the net present value of the lifetime fuel savings (based on fuel price excluding taxes). This formula differs from the one prescribed by the methodology developed in chapter 2, which is based on calculating the annuity of the investment and subtracting the change in annual fuel costs (and possible other operating costs), but is expected to give similar results.

For calculating the net present value an interest rate of 4% is used in line with the prescribed procedures for impact assessments performed by the European Commission. For vehicle technologies applied to passenger cars a constant average annual mileage of 16,000 km and an average vehicle lifetime of 13 years are assumed for the calculation of abatement costs. For other options the lifetime may be different. It could be argued that in the calculation of net present value of the lifetime fuel savings the annual mileage should be differentiated over time to reflect that new cars generally drive more kilometres per year than older cars. However, since this is a first order assessment of CO_2 abatement costs, and since the above formula with constant yearly fuel savings is applied equally to all options under study, the proposed simplified approach is deemed sufficient.

Fuel cost savings are based on the real-world fuel consumption which is assumed to be 1.195 times the TA value. The CO_2 reduction is also based on the real-world CO_2 emission, calculated from the TA value using a factor of 1.195, and furthermore includes the avoided WTT CO_2 emissions.

Lifetime fuel cost savings are dependent on the fuel cost (fuel price excl. taxes). In this chapter CO_2 abatement costs are generally calculated for 4 different scenarios assuming different values for the oil price and related costs of fuels. Data on oil price and costs of petrol/diesel are given in Table 15. The values for oil prices of 25 and 50 €/bbl are based on Concawe (2006), which uses the same two oil price scenarios. Gas costs in this table are price at the filling station excluding taxes and including the amortised costs of infrastructure. The values printed in italic have been calculated from these values assuming a linear relation between fuel costs and oil price. The value of 0.30 €/l for the costs of petrol/diesel (price excl. taxes) was used in IEEP (2004). The value of 0.60 €/l for the costs of petrol/diesel is added as an extreme scenario.

oil price [€/bbl]	petrol/diesel cost [€/l]	gas cost [€/m^3]
25	0.21	0.32
36	*0.30*	*0.40*
50	0.41	0.49
74	*0.60*	*0.65*

Table 15 Oil price and fuel cost values assumed for CO_2 abatement costs calculations

Translation from Type Approval to real-world CO_2 emission

The real-world (RW) emissions and fuel consumption of vehicles generally differs significantly from the values measured on the Type Approval (TA) test using the NEDC driving cycle and the prescribed test conditions. A description of the physical aspects that determine this difference and an assessment of the average quantitative relation between RW and TA fuel consumption and CO_2 emissions is presented in the Annex to chapter 5.2. In this study an average factor of 1.195 is used. Obviously this factor may change as a result of CO_2 reducing technologies that e.g. affect the ratio between part-load and full-load efficiency of the powertrain but this aspect is difficult to quantify within the aggregated approach of this study and is therefore neglected. The issue may require further study in a future project. The limited availability of hybrids and other advanced powertrains does not yet allow a statistically sound identification of a possible difference in the translation factor from type approval to real-world between these vehicles and vehicles with more conventional power trains.

Calculating Well-to-Wheel CO_2 emissions

Besides the direct CO_2 emissions from the exhaust the use of a vehicle also cause indirect CO_2 and other greenhouse gas emissions emanating from the fuel chain. Direct emissions are referred to as tank-to-wheel (TTW) emission, while the emissions from the fuel chain are called well-to-tank (WTT) emissions. The sum of the two are the well-to-wheel (WTW) emissions resulting from the mining and transport of raw energy carriers, the production and distribution of fuels and the consumption of fuel in the vehicle. Emissions of different greenhouse gases (CO_2, CH_4, N_2O as well as e.g. CFCs and HFCs used as airco refrigerants) are expressed and added in CO_{2eq} by multiplication with a Greenhouse Warming Potential (GWP).

For calculating WTW greenhouse gas emissions this study generally uses factors based on Concawe (2006). The factors for translating TTW CO_2 emissions into WTW CO_2 emissions are given in Table 16. In various analyses on “average” vehicles a sales-weighted average WTW/TTW factor of 1.183 is used, based on a 50%/50% share of petrol and diesel in the fleet.

	TTW		WTT			WTW
	CO_2-content [gCO_2/MJ_fuel]	lower heating value (LHV) [MJ/l_fuel]	WTT energy consumption [MJ/MJ_fuel]	WTT CO_2-emission [gCO_2/MJ_fuel]	WTT CO_2-emission [gCO_2/gCO_2_TTW]	WTW CO_2-emission [gCO_2/gCO_2_TTW]
petrol	73.40	32.2	0.14	12.5	0.170	1.170
diesel	72.80	35.8	0.16	14.2	0.195	1.195

Table 16 Data on the WTW greenhouse gas emissions from petrol and diesel derived from Concawe (2006).

Calculation of overall CO_2 reduction for EU15

In order to be consistent with the TREMOVE calculations to be performed on the basis of the output of the TNO (2006) study, it was decided to calculate the overall CO_2 reduction potential of various measures using a fleet spreadsheet on the basis of output data on vehicle stock, annual mileage and baseline CO_2 emission from TREMOVE (see TREMOVE). At the time of these calculations TREMOVE 2.42 baseline data were available for EU15 only. All CO_2 reduction potential assessments presented in TNO (2006) therefore relate to EU15.

The fleet spreadsheet used contains for the years 1995, 2000, 2002, 2005, 2008, 2009, 2010, 2011, 2012, 2015 and 2020 data on the vehicle stock specified in:

- number of vehicles of different ages (for some calculations (e.g. NGVs) also a distinction between petrol and diesel vehicles was used);
- annual mileage for vehicles of different ages;
- real-world CO_2 emission for vehicles of different ages (in TREMOVE based on COPERT III).

Such a spreadsheet allows modelling of the effect of the gradual penetration of new technologies into the fleet through the sales of new vehicles, taking account of the fact that new vehicles drive more kilometres per year than older vehicles, but also allows the assessment of effect of measures that target the entire fleet. CO_2 emission reduction potentials are calculated for the different years in Mtonnes/a by subtracting the emissions produced under certain scenario assumptions from the emissions produced in the baseline situation. Overall emissions are calculated by means of the sumproduct of the number of vehicles, the annual mileage and the CO_2 emission in g/km of vehicles of different ages in the fleet.

It should be noted here that the CO_2 reduction potential as calculated in this study is only a first indication of the overall CO_2 reduction potential of the measures under study. The CO_2 reductions are calculated ex-ante without considering market reactions. A more definitive assessment of CO_2 reduction potentials for the various measures will be performed using the TREMOVE-model.

As stated above CO_2 reduction potentials are only assessed for EU15. However, the objective of the EU policy is to reach an EU25 average of 120 g CO_2/km. Based on 2004 monitoring results, EU10 average emissions are at 156 gCO_2/km, compared to an EU15 average of 163 gCO_2/km, leading to an EU25 average of 162 g CO_2/km. Including the new countries into the assessment would thus result in somewhat smaller average values for the EU25 new vehicle sales averaged CO_2 emission. This effect could not be taken into account in TNO (2006), not even in an indicative way. The car market in the new EU countries is a growing market in contrast to the rather saturated market in EU15. As a consequence the optimal solution for reaching a 2012 target may be different for the EU25 than for EU15. Projections on the development of this growing market should be made in order to properly assess the future average new vehicle CO_2 emissions for EU25. Given the lack of readily available data on this market such an analysis was considered beyond the scope of this study.

Translation of EU15 data to EU25

To allow comparison of the outputs of TNO (2006) to the data developed in this study for other sectors they have to be made consistent with the baseline used and translated from EU15 to EU25. Due to lack of data only a simplified approach could be worked out. The first step is to scale the calculated reduction potentials from TNO (2006) (as based on TREMOVE data) to a level consistent with the EU15 PRIMES data used in this study, by multiplication with the ratio between the total emissions from passenger cars as derived from both data sources. The second step then is to multiply the result with the ratio between total CO_2 emissions from EU25 and EU15 as derived from PRIMES data. This is summarized in the formula below:

$$\begin{aligned}\mathit{Potential\ EU25}_{PRIMES} = {} & \mathit{Potential\ EU15}_{TREMOVE} * (\mathit{Total\ EU15}_{PRIMES} / \mathit{Total\ EU15}_{TREMOVE}) * \\ & (\mathit{Total\ EU25}_{PRIMES} / \mathit{Total\ EU15}_{PRIMES}) \qquad (5.2)\end{aligned}$$

An analysis of the factors to be used is given in Table 17. The overall translation factor is close to 1, which results from the fact that the total EU15 emissions estimated by PRIMES is smaller than the total EU15 emissions from passengers estimated by TREMOVE.

Private cars

variable	source	unit	1990	1995	2000	2005	2010	2015	2020	average
final energy demand	PRIMES EU-15	[ktoe]	128127	134835	144654	153131	152909	146788	149979	
final energy demand^1	PRIMES EU-15	[MJ]	5.4E+12	5.6E+12	6.1E+12	6.4E+12	6.4E+12	6.2E+12	6.3E+12	
CO_2-emission^2	PRIMES EU-15	[Mtonne CO_2]	392	412	442	468	468	449	459	
CO_2-emission^3	TREMOVE EU-15	[Mtonne CO_2]		491	523	534	516	507	513	
translation factor	PRIMES EU-15/TREMOVE EU-15			0.84	0.85	0.88	0.91	0.89	0.89	**0.90**
final energy demand	PRIMES EU-25	[ktoe]	136369	144276	156217	167034	167796	162038	166582	
translation factor	PRIMES EU-25/PRIMES EU-15		1.06	1.07	1.08	1.09	1.10	1.10	1.11	**1.10**
translation factor	PRIMES EU-25/TREMOVE EU-15			0.90	0.91	0.96	0.99	0.98	0.99	**0.99**

^{1}) 1 ktoe = 4.19 10^7 MJ

^{2}) CO_2-content petrol/diesel = 73 g/MJ

^{3}) TREMOVE data used for [TNO 2006]

Table 17 Translation of EU15 data from TNO (2006) to EU25 data, consistent with the PRIMES methodology.

5.1.3. COMPARISON OF METHODOLOGICAL ASPECTS WITH BLOK-STUDY AND TREMOVE

Comparison with the Blok-Study

Formula for calculation of CO_2-abatement costs: The methodology for calculating CO_2-abatement costs as used in [TNO 2006] is summarized by formula 5.1 as presented above. The Blok-study (see e.g. [AEA 2001] for the report on the transport sector), which is used as the basic source for CO_2-abatement costs for reduction options in other sectors, uses a methodology for calculating CO_2-abatement costs that is based on the following generalized formula:

$$CO_2\text{-abatement costs} = \frac{I^{an} + \Delta_{\text{O\&M}} - \Delta_{\text{ann. fuel costs}} - \text{secondary benefits}}{\text{yearly } CO_2\text{-reduction}} \qquad (5.3)$$

with $\Delta_{\text{O\&M}}$ the additional operation and maintenance costs per year and $\Delta_{\text{ann. fuel costs}}$ the annual fuel cost savings. The additional operation and maintenance costs and the secondary benefits are generally negligible for transport technologies. Both in the TNO-study and in the Blok-study these aspects are therefore not taken into account. I^{an} is the annuity of the total investment costs:

$$I^{an} = I * \frac{(1+r)^{lt} * r}{(1+r)^{lt} - 1} \qquad (5.4)$$

In this equation lt is the lifetime of the measure, r is the discount rate and I is the total investment costs.

Similar to the TNO-study the Blok-study assumes a discount rate of 4%. For vehicle lifetime the Blok-study assumes 12 years, whereas the TNO-study assumes 13 years. In the calculation of fuel costs savings the annual mileage and the fuel costs are important assumptions. The Blok-study uses 13,679 km for the annual mileage and a fuel price of €1990 0.162 per litre for petrol and €1990 0.172 per litre for diesel. The TNO-study assumes an annual mileage of 16,000 km and calculates fuel cost savings for four different levels of fuel costs ranging from €2002 0.21 per litre to €2002 0.60 per litre for both petrol and diesel.

In literature both approaches (formula's 5.1 and 5.3) are found to be applied, although in hindsight there seems to be a preference for the methodology as used by Blok. Comparing these formula's for the same set of input data shows that e.g. for the case of r = 4% and lt = 12 j the formula 5.3 yields results that are a constant factor 1.28 higher than the results of formula 5.1 irrespective of the values of *I* and $\Delta_{\text{ann. fuel costs}}$.

From an economist's point of view this difference between the two approaches can be considered negligible. Given the uncertainties in cost assessments the issue is whether abatement costs are 10 or 100 €/tonne rather than 10 or 13 €/tonne. Therefore, even though there formally is a slight inconsistency between the methodology for assessing CO_2-abatement costs for options applicable to passenger cars and vans as used in the TNO-study and the methodology applied in the Blok-study to CO_2-reduction options in other sectors, it has been decided that a recalculation of the results of [TNO 2006] using formula 5.2 is not necessary.

Comparison with TREMOVE: "1st order" vs. "2nd order" calculation of abatement costs

Both [TNO 2006] and [AEA 2001] calculate CO_2-abatement costs in what could be labelled as a "1st order approach". This comprises two aspects. The first one is that only investment costs and fuel cost savings are taken into account, which in general is a simplification when compared to a full cost benefit analysis. The second aspect is that the methodology assumes that "all else remains equal" in the sense that abatement costs are assessed at the vehicle level for a given vehicle segment or a fixed definition of the average vehicle as well as for a fixed annual mileage. This implicitly assumes that changes in vehicle price or cost of ownership as a result of applying CO_2-reducing measures do not influence vehicle purchasing behaviour nor mobility behaviour. In reality changes in price obviously also cause changes in the demand for vehicles in general, the demand for vehicles in different segments, in the total car mobility and in the modal split. These aspects are all taken into account in dynamic models such as TREMOVE.

TREMOVE calculates the impact of price changes (both vehicles, fuels and taxes) on the vehicle fleet composition and mobility and then calculates the CO_2-abatement costs by dividing the total additional costs to society (in a given year for a specific country or the EU as a whole) by the total change in annual CO_2-emissions of the transport sector. In this calculation also additional benefits are taken into account such as a possible reduction of the external costs of NOx-emissions resulting from a reduced mobility. The TREMOVE approach thus takes dynamic interactions between vehicle costs and the overall transport system into account and can be labelled as "2nd order".

For CO_2-reduction measures that yield net cost reductions at the level of consumers TREMOVE will generate a higher estimate of the abatement costs than the "1st order" approach described above, as lower prices result in increased mobility which counteracts some of the CO_2-emission reductions (in g/km) achieved at the vehicle level. Similarly, for CO_2-reduction measures that increase the net costs at the level of consumers TREMOVE will generate a lower estimate of the abatement costs than the "1st order" approach, as higher prices reduce mobility which generates further overall CO_2-emission reductions.

Estimation of CO_2-reduction potentials

According to [AEA 2001] (see p. 55) in the Blok study "the CO_2-reduction which might be achieved by each measure is estimated by estimating the date at which the measure might become available, and how quickly the measure is implemented after this and using these data to estimate the proportion of the fleet in 2010 which will be affected by the measure". In general terms this approach is consistent with the approach used in [TNO 2006]. Obviously differences will exist in the precise assumptions of feasible levels of fleet penetration of various options.

The translation of CO_2-reduction potentials for EU-15 as calculated in [TNO 2006] to the EU-25 level as used in this study is described above. Compared to [TNO 2006] also at the EU-15 level CO_2-reduction potentials for some options (e.g. eco-driving and low rolling resistance tyres) have been recalculated on the basis of new assumptions on fleet penetration levels that are more consistent with the approach used for all sectors in the scenarios worked out for this study. The assumptions made in [TNO 2006] can be characterised as "conservatively realistic" while in this study the aim is to estimate a maximum potential based on more "optimistically realistic" assumptions.

CO_2-reduction potentials are always estimated in comparison to a baseline scenario. According to [AEA 2001] the Blok-study has used two different baselines, i.e. one excluding and one including the "ACEA-agreement" . It is not clear how the use of two different baselines is worked out in the overall analysis for all sectors together. However, as for this study a new baseline has been developed (based on new PRIMES data, see chapter 7) and as the data based on the TNO-study fully replace the data on transport options as worked out in the Blok-study and as the data for all sectors are updated in order to be consistent with the general overall approach as defined for this study, a further analysis of differences between the TNO-study and the Blok-study concerning CO_2-reduction potentials of measures taken in the transport sector is not meaningful. The new baseline (scenario 0, see chapter 7) used in this study assumes that the target of the ACEA-agreement is met and that CO_2-emission factors remain constant after 2008/9, but does not assume any further tightening to e.g. 120 g/km after 2008/9. Also in scenario 1 (see also chapter 7), in which the effects of planned but not yet implemented policy measures are included, no policy measures for CO_2-reduction of passenger cars and vans beyond 2008/9 have been assumed.

5.1.4. TECHNICAL OPTIONS TO REDUCE FUEL CONSUMPTION AT THE VEHICLE LEVEL

Under this heading technical options have been evaluated which can be applied to new vehicles in the 2002 – 2012 timeframe. Only options are considered which affect the vehicle's CO_2 emission as measured on the type approval test. The options considered are listed in Table 18. Based on a review of available literature and input from industry by means of a questionnaire and additional meetings, for each of the options the additional costs and CO_2 reduction potential (expressed as a % reduction relative to the CO_2 emissions of the 2002 baseline vehicle) have been estimated. Separate estimates are made for application of these options to small, medium size and large passenger cars. Detailed data are not repeated here, but can be found in TNO (2006).

	Petrol vehicles	Diesel vehicles
Engine	Reduced engine friction losses	Reduced engine friction losses
	DI / homogeneous charge (stoichiometric)	4 valves per cylinder
	DI / Stratified charge (stoichiometric)	Piezo injectors
	DI / Stratified charge (lean burn / complex strategies)	
	Mild downsizing with turbocharging	Mild downsizing
	Medium downsizing with turbocharging	Medium downsizing
	Strong downsizing with turbocharging	Strong downsizing
	Variable Valve Timing	
	Variable valve control	
	Cylinder deactivation	Cylinder deactivation
	Variable Compression Ratio	
	Optimised cooling circuit	Optimised cooling circuit
	Advanced cooling circuit + electric water pump	Advanced cooling circuit + electric water pump
		Exhaust heat recovery
Transmission	Optimised gearbox ratios	6-speed manual/automatic gearbox
	Piloted gearbox	Piloted gearbox
	Continuous Variable Transmission	Continuous Variable Transmission
	Dual-Clutch	Dual-Clutch
Hybrid	Start-stop function	Start-stop function
	Regenerative braking	Regenerative braking
	Mild hybrid (motor assist)	Mild hybrid (motor assist)
	Full hybrid (electric drive)	Full hybrid (electric drive capability)
Body	Improved aerodynamic efficiency	Improved aerodynamic efficiency
	Mild weight reduction	Mild weight reduction
	Medium weight reduction	Medium weight reduction
	Strong weight reduction	Strong weight reduction
Other	Low rolling resistance tyres	Low rolling resistance tyres
	Electrically assisted steering (EPS, EPHS)	Electrically assisted steering (EPS, EPHS)
	Advanced aftertreatment*	DeNOx catalyst*
		Particulate trap / filter*

*) These options are not CO_2 reduction options, but are included as technical measures that need to be added to some of the CO_2 reduction options to make them compliant with future exhaust gas emission limits. The aftertreatment options by themselves also have an impact on CO_2 emissions.

Table 18 Technical options to improve fuel economy and reduce CO_2 emissions of passenger cars on petrol and diesel in the period between 2002 and 2012

Methodology

Many of the options listed in Table 18 can be combined into packages for which the overall costs and CO_2 reduction are calculated. The large number of options listed in Table 18 leads to a very large number of possible packages of compatible measures. Here a brief summary is given of the methodology that is used:

- to derive continuous cost curves based on the cost and reduction figures derived for the various possible packages;
- to assess overall costs of reaching a certain type approval based CO_2 reduction target on the basis of applying these cost curves to all manufacturers selling vehicles on the European market.

In the assessment presented in TNO (2006) basically the same models and methodology as developed for IEEP (2004) have been used. The models have been updated with new input data on cost and CO_2 reduction potentials and where appropriate adapted assumptions on e.g. autonomous trends.

Construction of cost curves:

- identification of the average 2002 baseline vehicle (in terms of applied technology, mass, CO_2 emission, costs, etc.) for small / medium / large passenger cars on petrol and diesel;
- identification of technical options for CO_2 reduction to be applied after 2002;
- quantification of the CO_2 reduction potential and additional costs of each individual technical option;
- identification of (all) possible packages in which two or more of the above technical options can be combined in a vehicle;
- determination of the overall CO_2 reduction potential (in [%] compared to baseline) and additional costs (in [€]) of each possible package;
- determination per vehicle segment of a continuous cost curve describing additional costs as a function of CO_2 reduction (in [g/km]), based on the above assessment of the overall CO_2 reduction potential and additional costs of each possible package.
-

Figure 10 gives an example of how continuous cost curves are drawn on the basis of the cloud of data points generated by all possible combinations of options as listed in Table 18.

The overall CO_2 emission of a vehicle with a package of n CO_2 reducing options is estimated as:

$$CO_2^{package} = CO_2^{baseline} \times \prod_{i=1}^{n} (1 - \delta_i)$$

with δ_i the relative CO_2 emission reduction (in [%]) of technical option i.

The additional costs of a vehicle with a package of n CO_2 reducing options are calculated as:

$$cost^{package} = \sum_{i=1}^{n} cost_i$$

with $cost_i$ the additional cost of technical option i.

Obviously the above formula for assessing the overall CO_2 reduction potential is a rough estimation which may overestimate the overall reduction achieved by two measures that target the same losses. As an example, in a combination that includes both engine down sizing and drivetrain hybridisation the first option improves the engine's part load efficiency while the second option aims to avoid the occurrence of part load operation. The overall efficiency improvement of the combination of the two options will be smaller than the product of the efficiency improvements estimated for the individual options applied separately to a baseline vehicle. The estimation of the reduction potential of a package of options can be estimated correctly by means of dynamical computer simulation of a vehicle comprising the package of options over a driving cycle. This, however, is a time consuming and information intensive exercise which could only be performed for a limited number of packages. As there are several thousands of possible combinations of two or more of the options listed in Table 18 a more straightforward approach has been adopted in IEEP (2004) and TNO (2006), in which the CO_2 reduction potential of each package is roughly estimated with the above formula, while the effect of overestimating the overall CO_2 reduction potential is compensated by the way in which the cost curve is determined on the basis of the costs and CO_2 reduction potentials of a large number of packages in a way as is described below.

In Figure 10 the pink dots represent the costs vs. net CO_2 reduction of the various feasible packages, based on estimates of manufacturer costs. The blue line represents the constructed cost curve. Starting point for the x-axis in these figures is the TA CO_2 emissions value for the 2002 average baseline vehicle for this segment. Starting point for the y-axis in these figures is 0.60 times the average consumer price value for the 2002 average baseline vehicle of the given class. It should be noted that in the cost assessment model the cost curves are applied separately to the different manufacturers using the 2002 values for TA CO_2 emissions and vehicle costs for the individual manufacturers as starting points (based on Polk Marketing Data for 2002).

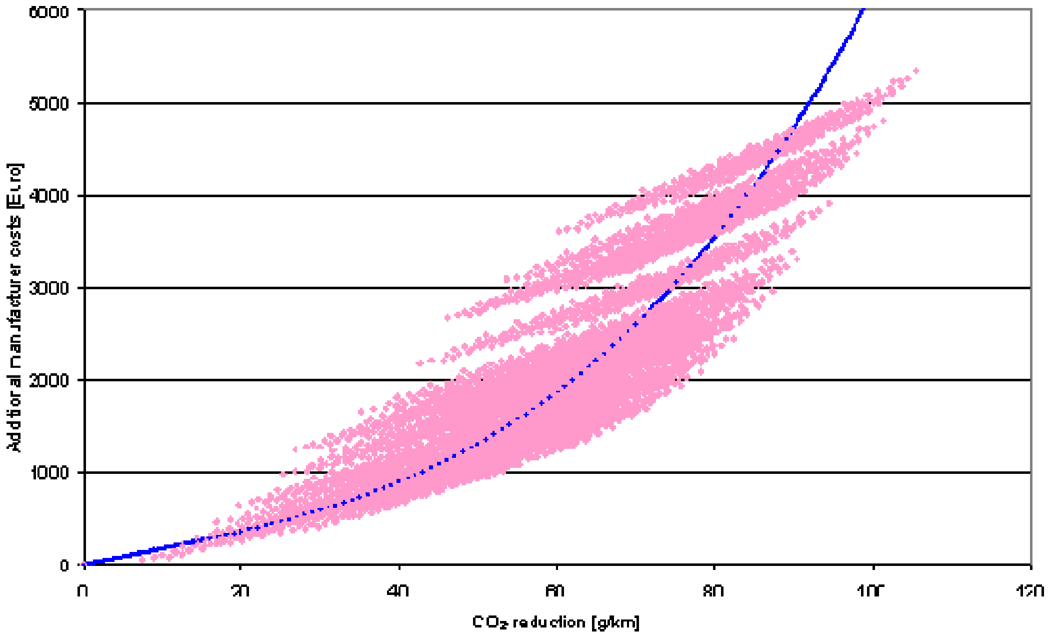


Figure 10 Cost curve for medium size petrol cars (manufacturer costs as a function of reduction of Type Approval CO_2 emission). Starting point for the x-axis is the TA CO_2 emission of the 2002 baseline vehicle: 183.7 g/km.

The cost curve (blue line) are drawn to follow the curvature of the "cloud" of data points at a certain distance from the outer envelope. This distance serves as a safety margin to account for the fact that simply combining the CO_2 reduction potential of individual measures as defined above tends to overestimate overall CO_2 reduction potential of the complete package. The cheapest packages are also not necessarily the technical solutions that yield optimal driveability or meet other design goals besides CO_2 emission reduction, and may therefore not be the optimal solution from a broader design point of view or may be more difficult to market. For this assessment the cost curves are positioned in such a way that roughly 2/3 of the data points is on the left side of the curve and 1/3 on the right side. This margin is somewhat larger than was used in IEEP (2004), in order to better account for possible overestimations when combining e.g. the CO_2 reductions of hybrid power trains with those of advanced engine technologies (petrol DI, downsizing).

Cost curves are defined as 3rd order polynomials expressed as:

$$y = a\,x^3 + b\,x^2 + c\,x$$

with x the CO_2 reduction in [g/km] and y the costs in [Euro]. The resulting cost curves for the different passenger car vehicle segments are presented in Figure 11.

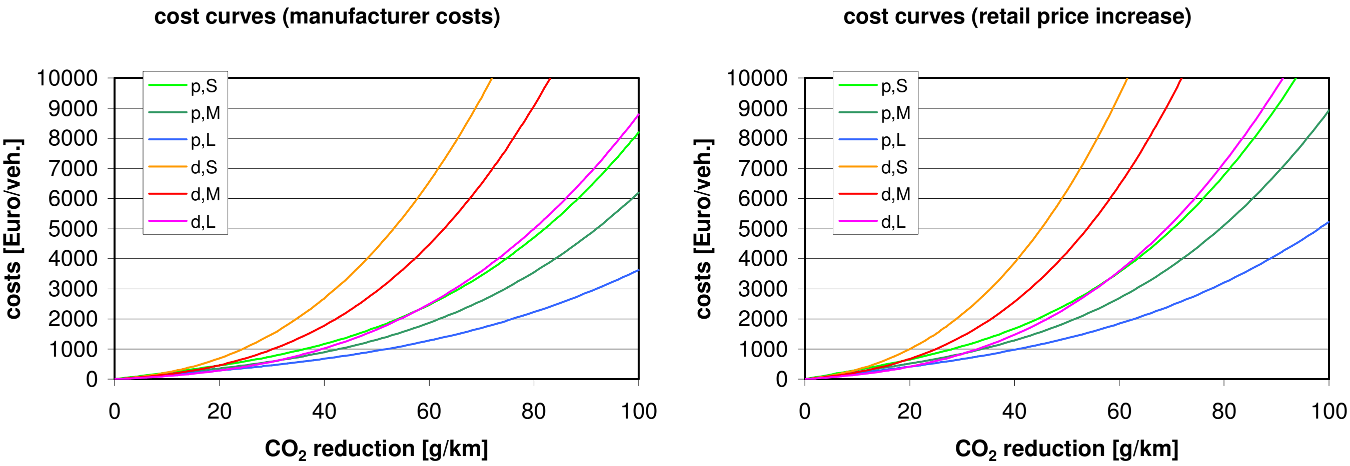


Figure 11 Cost curves based on manufacturer costs (left) and retail price (right) for reaching CO_2 reductions in the various vehicle segments. Starting points of the cost curves are the TA CO_2 emission values and vehicle costs of the 2002 average baseline vehicles for the different segments.

Assessment of the overall costs to reach a given type approval CO_2 target

- quantification of the 2002 situation per manufacturer in terms of the sales and average TA CO_2 emission per segment (for IEEP 2004 and TNO 2006 based on data from Polk Marketing Systems);
- quantification of assumptions on autonomous trends between 2002 and 2012:
  - sales increase
  - weight increase
  - shift from petrol to diesel
- assessment of the 2008/9 situation:
  - For calculating the required reductions per car per segment, it is assumed that the 2008 goal will be reached in such a way that the total costs for the members of an association (ACEA / JAMA /KAMA) are minimal and that per segment all manufacturers realise the same reduction per car. This way the costs per car in a given segment are the same for all manufacturers, so that the burden is shared in a fair way. The reductions per car for each segment are found using a solver function which minimises the total costs (costs for realising 140g/km in 2008, starting from the base year 2002) for the association "bubble" by varying the reductions per car for the six segments under the condition that the resulting average emission per car in 2008 is 140g/km. When this minimum is reached, the reductions per car per segment are such that the marginal costs are equal for all segments.
- assessment of the 2012 situation:
  - specification of a target-measure combination: Calculations are done for the following 18 (= 3 + 3 + 3*4) options of target-measure combinations:
    - car based targets:
      - fixed target per car

    - percentage reduction target per car
    - four different versions of utility based targets per car
  - manufacturer based targets
    - fixed target per manufacturer
    - percentage reduction target per manufacturer
    - four different versions of utility based targets per manufacturer
  - manufacturer based targets with allowing trading of CO_2 credits
    - fixed target per manufacturer including the possibility of emission trading
    - percentage reduction target per manufacturer including the possibility of emission trading
    - four different versions of utility based targets per manufacturer including the possibility of emission trading

› calculation of the costs for reaching the specified 2012 target:

  - For the car based targets this is a straightforward calculation of the required reduction per segment and the associated costs on the basis of the cost curve, carried out for each manufacturer separately;
  - For the manufacturer based targets (without and with trading) this involves a cost optimisation routine, applied to each manufacturer separately, using a solver function that finds the distribution of CO_2 reductions over the various vehicle segments that yields the lowest costs for reaching the target;

› In the assessment of the 2008 and 2012 situation the effects of sales trends, autonomous weight increase and the shift from petrol to diesel are accounted for.

A more elaborate description of the applied model and methodology can be found in IEEP (2004) and TNO (2006).

The target-measure combinations in which trading of CO_2 credits is allowed among manufacturers are assessed under the assumption of a fully transparent market with a high number of participants. Whether these assumptions are justified and whether the costs of setting up a trading system outweigh the potential benefits needs to be analysed in a future project (i.e. in case trading is considered a promising ingredient of a future EU CO_2 policy for passenger cars).

Results presented in this chapter represent average results for the manufacturer based target / measure combinations without trading.

CO_2 abatement costs

Results from TNO (2006) with respect to costs per vehicle and CO_2 abatement costs of technical measures applied to new passenger cars are summarized in Figure 12 and Figure 13. The latter graph presents the average abatement costs, based on vehicle and fuel prices exclusive of taxes, for reaching various targets for the sales-averaged type approval CO_2 emissions of new vehicles in 2012. The cost assessment includes the assumption that autonomous trends result in a 1.5% p.a. weight increase of vehicles if no technical measures are applied. This is the origin of the finite costs per vehicle of maintaining 140 g/km until 2012: The autonomous weight increase results in additional CO_2 emissions which need to be compensated by the application of CO_2-reducing measures.

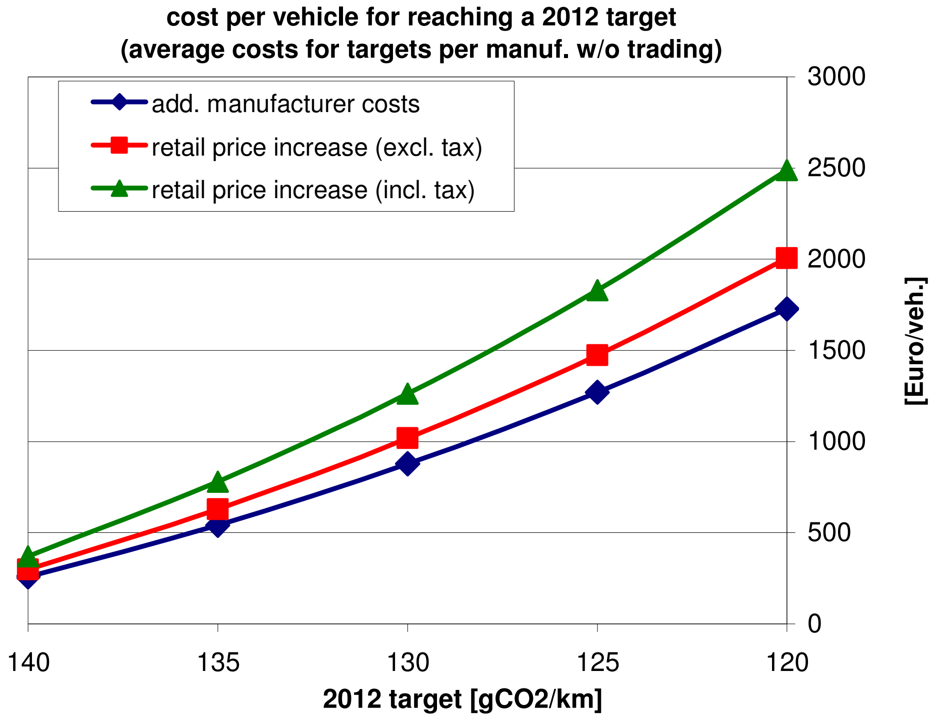


Figure 12 Average additional costs per vehicle for reaching various 2012 targets compared to the 2008 situation for targets applied per manufacturer without trading.

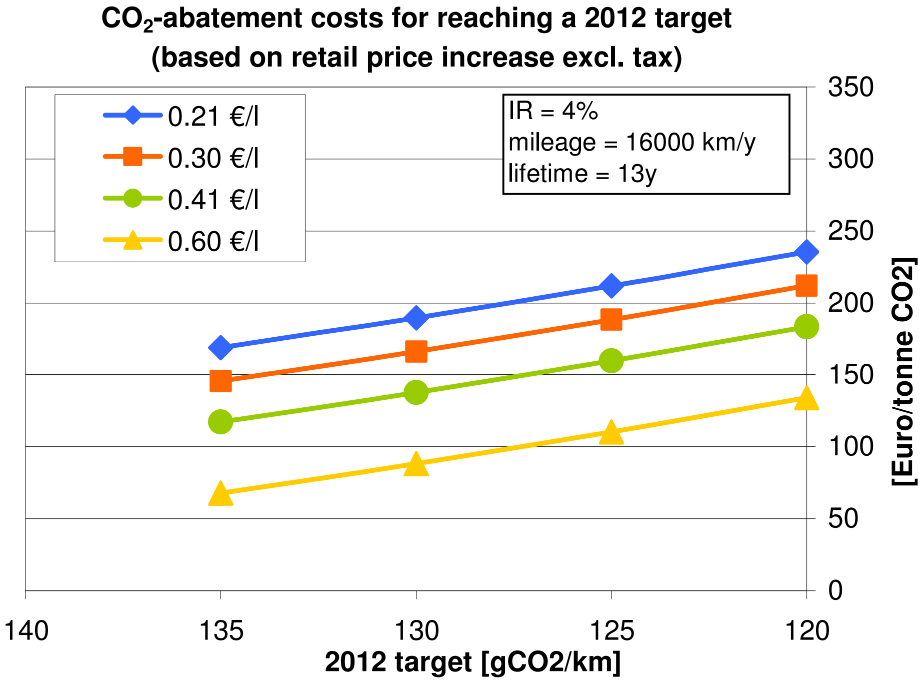


Figure 13 CO_2 abatement costs of reaching various 2012 targets, depending on fuel costs. In the CO_2 abatement cost formula investment costs are retail price increases excl. tax. Fuel cost savings are based on real-world fuel consumption and CO_2 emission reduction includes Well-to-Tank GHG emissions.

For the purpose of drawing MAC-curves for this study the above results for the average abatement costs for reaching various targets have been translated into marginal avoidance costs for consecutive steps of 5 g/km CO_2 emission reduction. These results are displayed in Table 19.

Oil price €/bbl	MAC in €/tonne for a reduction from .. g/km to .. g/km 140-135	135-130	130-125	125-120
25	169	210	256	306
36	146	187	233	283
50	117	158	204	254
74	68	109	155	205

Table 19 Marginal abatement costs for consecutive steps of 5 g/km CO_2 emission reduction in passenger cars

Reduction potential for EU15

The overall reduction potential in Mtonnes/a for the EU15 of reducing the average TA CO_2 emissions of passenger cars is assessed using a vehicle stock spreadsheet containing time series of data on the number of vehicles of different years of construction in the fleet, their average CO_2 emission and their average annual mileage. The overall reduction will evolve over time and is calculated for the period 2008 to 2020. Outside the context of TNO (2006) TREMOVE calculations will be used to calculate the overall reduction in more detail, also taking into account impacts of changes in vehicle prices on sales of different vehicle types, modal split and transport volumes.

The annual well-to-wheel GHG emission reduction (in Mtonnes CO_{2eq}/a) resulting from technical measures applied to passenger cars in order to reach 2012 targets of 135, 130, 125 and 120 g/km (sales average based on Type Approval test results) is displayed in Figure 14.

Type Approval values for intermediate years between 2009 and 2012 have been determined by means of linear interpolation. After 2012 the Type Approval CO_2 emission of new vehicles is assumed to remain constant at the 2012 level. Real-world CO_2 emissions in the policy scenarios for the different target values have been determined using scaling factors based on the development of Type Approval values between 2009 and 2012 which are applied to the real-world CO_2 emission factors as included in the TREMOVE baseline data. Calculations of the overall reduction include well-to-tank emissions based on Concawe (2006).

As can be seen from Figure 14 the overall reduction resulting from measures taken between 2008 and 2012 still increases after 2012 as the share of vehicles meeting the 2012 target in the fleet is still increasing after 2012. For the 135 g/km target a decrease is visible after 2015. This is caused by the fact that the TREMOVE baseline includes some autonomous efficiency improvements between 2009 and 2020, while in the policy scenarios emissions of new vehicles are assumed constant after 2012. The motivation for the latter is that technical options that may be used in the autonomous developments assumed in the TREMOVE baseline scenario are used earlier in the policy scenario for reaching the 2012 target.

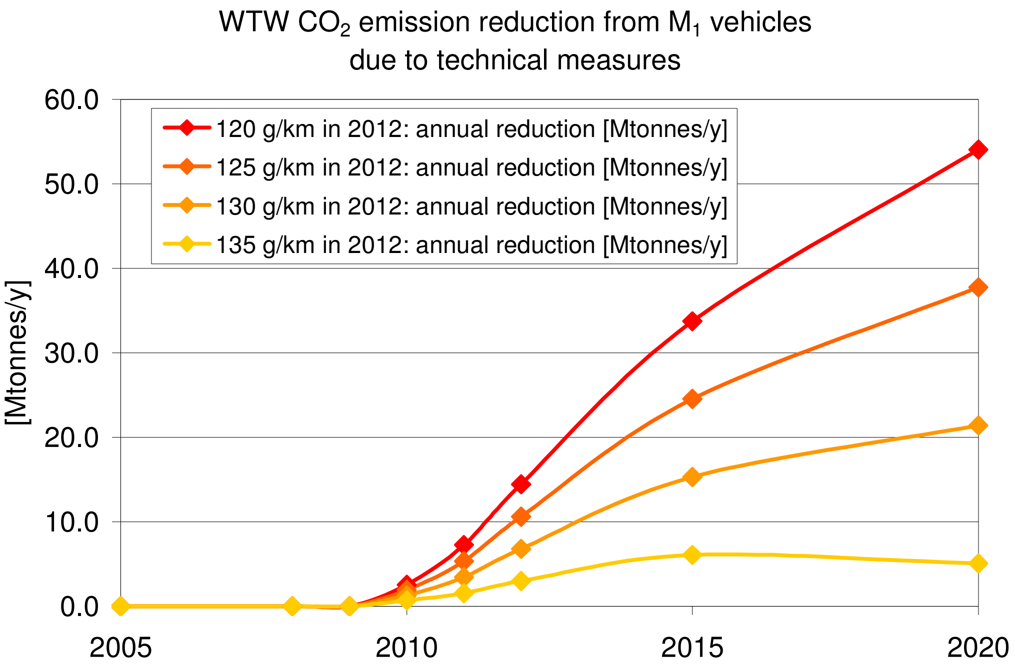


Figure 14 Annual well-to-wheel GHG emission reduction (in Mtonnes CO_{2eq}/a) for EU15 resulting from technical measures applied to passenger cars in order to reach a 2012 target between 135 and 120 g/km.

5.1.5. APPLICATION OF FUEL EFFICIENT AIR CONDITIONING SYSTEMS

The EC has proposed several measures to reduce greenhouse gas emissions from passenger cars in the next decade. The EC aims at reducing greenhouse gas emissions from mobile air-conditioning systems (MAirCo) by a ban on the high GWP R134a as a refrigerant for all mobile air conditioner systems as from 2011 for new types of vehicles and as from 2017 for new vehicles. As a result of this legislation, the auto industry is challenged to develop new systems which use low GWP refrigerants as an alternative to R134a. Parallel to these developments, the industry investigates possibilities to improve existing systems, as such legislation is not proposed for other parts of the world and as for the EU still some time has to be bridged before switching to alternatives. In TNO (2006) it is expected that CO_2-based systems (R744) will be the dominant alternative and that in response to existing policy these systems will gradually enter the market after 2008, reaching near 100% of new sales by 2014 or 2015. This baseline development is graphically displayed in Figure 15.

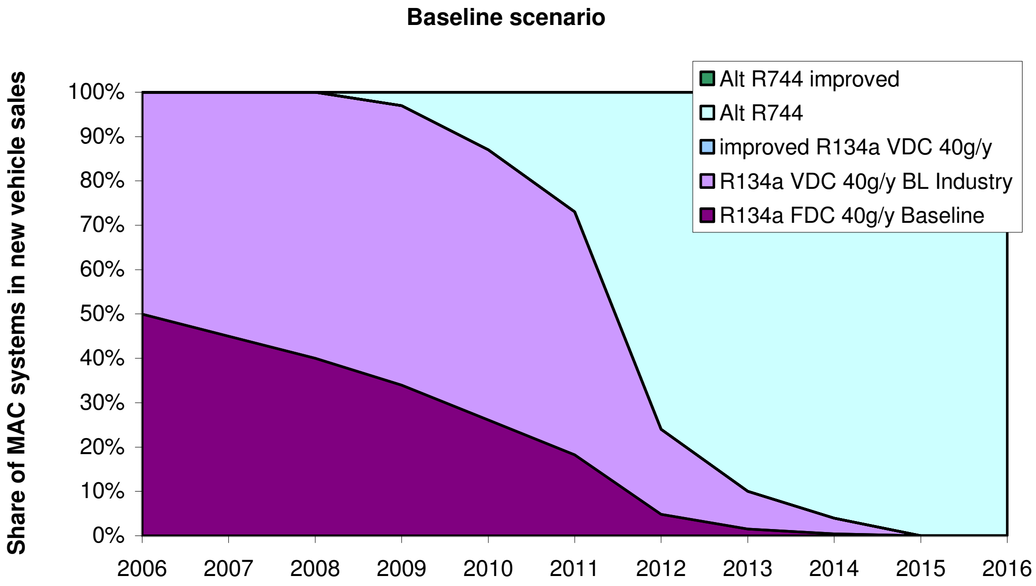


Figure 15 Development of the market share of different mobile AirCo-systems in the baseline scenario.

Both the existing R134a systems and the future R744 systems have room for improvement with respect to energy efficiency and the resulting indirect CO_2 emissions associated with use of these aircos. In response to a possible EU policy promoting energy efficiency of mobile air conditioning systems it is expected that improved systems will come to the market which have significantly lower energy consumption. The additional manufacturer costs for improved systems are estimated at €40 for R134a systems and €60 for R744 systems. Besides that further improvement of the average efficiency of R134a systems is expected to be achieved by an increased share of systems variable displacement compressors. This policy scenario is graphically displayed in Figure 16.

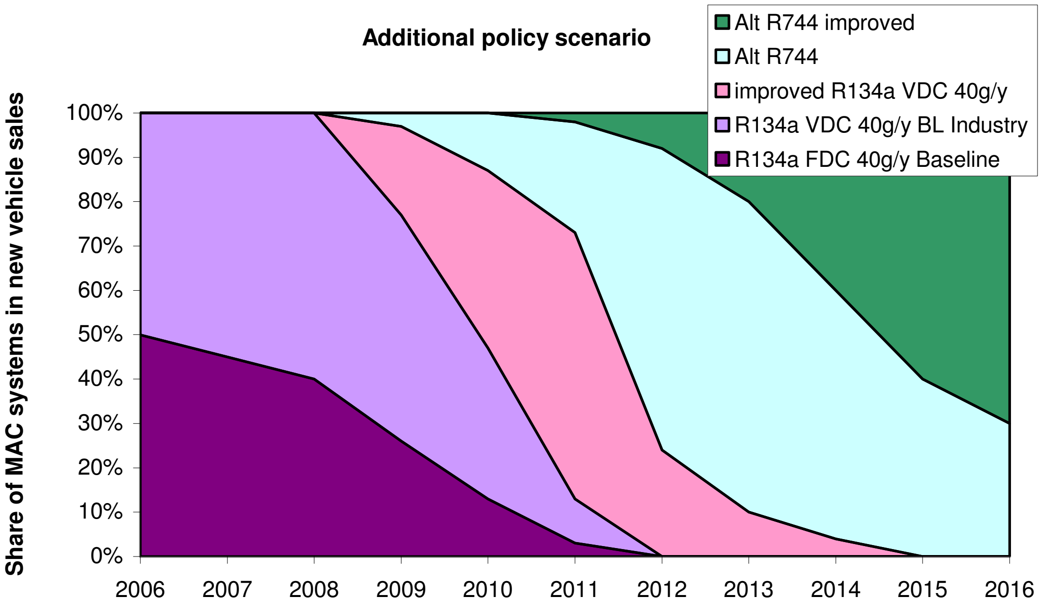


Figure 16 Development of the market share of different mobile AirCo systems in the additional policy scenario.

CO_2 abatement costs

Cost effectiveness of a policy promoting the introduction of more efficient mobile AirCo systems is assessed by estimating the total annual indirect CO_2 emissions, investment and fuel costs for a baseline scenario (describing the response to existing policy) and a constructed policy scenario sketching a possible response to a not yet defined EU policy aimed at the efficiency of mobile AirCo systems. The cost and efficiency figures for the various technical options are displayed in **Table 20**. It is important to note that developments influencing the direct GHG emissions of aircos (refrigerant emissions) are identical in both scenarios, so that refrigerant emissions do not play a role in the assessment of abatement costs for airco efficiency improvements.

	add. manuf. costs	relative efficiency	indirect TTW CO_2-emission [g/km]						
	[€]	[%]	2006	2007	2008	2009	2010	2011	2012
R134a FDC 40g/y baseline	0	100%	7.76	7.76	7.76	7.76	7.76	7.76	7.76
R134a VDC 40g/y (= BL industry)	35	70%	5.44	5.44	5.44	5.44	5.44	5.44	5.44
average R134a system			6.60	6.48	6.37	6.25	6.13	6.02	5.90
improved R134a VDC 40g/y	75	53%	4.08	4.08	4.08	4.08	4.08	4.08	4.08
Alt R744	135	56%			4.35	4.35	4.35	4.35	4.35
Alt R744 improved	195	42%			3.26	3.26	3.26	3.26	3.26

	add. manuf. costs	relative efficiency	indirect TTW CO_2-emission [kg/y]							direct refrigerant emission
	[€]	[%]	2006	2007	2008	2009	2010	2011	2012	[kg CO_2-eq./y]
R134a FDC 40g/y baseline	0	100%	124	124	124	124	124	124	124	52
R134a VDC 40g/y (= BL industry)	35	70%	87	87	87	87	87	87	87	52
average R134a system			106	104	102	100	98	96	94	52
improved R134a VDC 40g/y	75	53%	65	65	65	65	65	65	65	52
Alt R744	135	56%			70	70	70	70	70	0
Alt R744 improved	195	42%			52	52	52	52	52	0

*) annual mileage = 16000 km

Table 20 Reduction rates (TTW), additional manufacturer costs, indirect TTW CO_2 emissions and direct refrigerant emissions of various mobile AirCo systems as used in the baseline and additional policy scenario. Note that the average additional CO_2 emission due to use of an airco is derived from a mix of VDC and FDC systems and that a shift takes place from FDC to VDC systems over time. Also note that the industry uses VDC systems for the baseline whereas the calculations presented here use FDC systems for the baseline.

The abatement costs related to a policy promoting the use of more efficient air conditioning systems has been calculated by calculating the additional costs for the policy scenario and by subtracting the total annual CO_2 emissions related to airco use in the policy scenario from those in the baseline scenario. Results are displayed in Table 21. At low oil prices (25 to 35 €/bbl) the CO_2 abatement costs of reducing CO_2 emissions by means of energy efficient mobile AirCo systems vary between 40 and 90 €/tonne. At 50 €/bbl the CO_2 abatement costs vary between 15 and 40 €/tonne, becoming even negative for an oil price of 74 €/bbl. Compared to other technical options fuel efficient mobile AirCo systems therefore are a relatively cost-effective measure to reduce CO_2 emissions from passenger cars.

oil price [€/bbl]	fuel cost [€/l]	abatement costs [€/tonne] compared to baseline scenario				
		2008	2009	2010	2011	2012
25.0	0.21	--	56	60	66	90
36.3	0.30	--	33	36	42	66
50.0	0.41	--	4	7	14	37
73.8	0.60	--	-45	-42	-36	-12

Table 21 CO_2 abatement costs of the additional policy scenario compared to the baseline scenario for the various years between 2008 and 2012 and for different fuel costs.

For the moment there are no means for including the indirect fuel consumption of mobile AirCo systems in the type approval test. In TNO (2004a) a simplified test procedure has been developed to this end, but this procedure was found not to yield sufficiently reproducible and accurate results. The impossibility to include mobile AirCo systems in the TA test procedure for the moment seems to exclude legislative measures aimed at promoting airco efficiency. The existing procedure can be used as a monitoring tool accompanying a voluntary agreement with the automotive industry on airco efficiency.

CO_2 reduction potential for EU15

A first assessment, based on the above sketched baseline and policy scenario, of the overall reduction potential associated with promotion of the use of fuel-efficient air conditioner systems shows that for EU15 a total GHG reduction of 1.0 Mtonnes/a could be achieved in 2012 growing to 2.7 Mtonnes/a in 2020.

5.1.6. OPTIONS TO REDUCE VEHICLE AND ENGINE RESISTANCE FACTORS

Under this heading three options have been analysed in TNO (2006):

- low rolling resistance tyres (LRRT)
    - retrofit option for existing vehicles
- tyre pressure monitoring systems (TPMS)
    - to be applied to new vehicles
- low viscosity lubricants (LVL)
    - retrofit option for existing vehicles

The options have in common that they deal with reduction of resistance factors and that their effect is not visible on the type approval test. LRRT and LVL applied to new vehicles do affect the type approval CO_2 emissions and are therefore included in the options listed in Table 18.

CO_2 abatement costs

Based on an overview of information from literature, information provided by industry and expert judgement the costs, lifetime and CO_2 reduction percentage of LRRT, TPMS and LVL have been assessed in TNO (2006). The results are displayed in Table 22. The costs per unit product as well as the reduction percentage are very similar for the three options. The major difference in calculated CO_2 abatement costs is therefore caused by the difference in lifetime of the products. Tyres are on average replaced every 2.5 years. For LVL this is every year. A TPMS, however, has the same lifetime as the vehicle, which in TNO (2006) is assumed to be 12 years.

	cost per vehicle [€]	lifetime [y]	CO_2-reduction [%]	CO_2-abatement costs [€/tonne]			
oil price [€/bbl]				**25**	**36**	**50**	**74**
LRRT	49	2.5	3.0%	139	109	73	15
TPMS	58	12.0	2.5%	5	-20	-50	-98
LVL	20	1.0	2.5%	181	150	113	53

Table 22 Costs, reduction and CO2 abatement costs for LRRT, TPMS and LVL.

CO_2 reduction potential for EU15

CO_2 reduction potentials have been estimated using a fleet model based on TREMOVE data. In TNO (2006) for each of the options a feasible market penetration scenario has been constructed indicating how the product's market share could realistically evolve over time in response to implemented policies promoting the use of these options. For LRRT an autonomous trend was assumed going from a 50% market share in 2008 to 71% in 2020. In the policy scenario this share increases to 100% in 2020. For TPMS the market share in 2008 is assumed to be 5%, growing autonomously to 25% in 2020. In the policy scenario the share in 2020 is 88%. Similar numbers are assumed for the baseline and policy scenario in the case of LVL. These scenarios result in annual CO_2 reduction potentials as indicated in Figure 17.

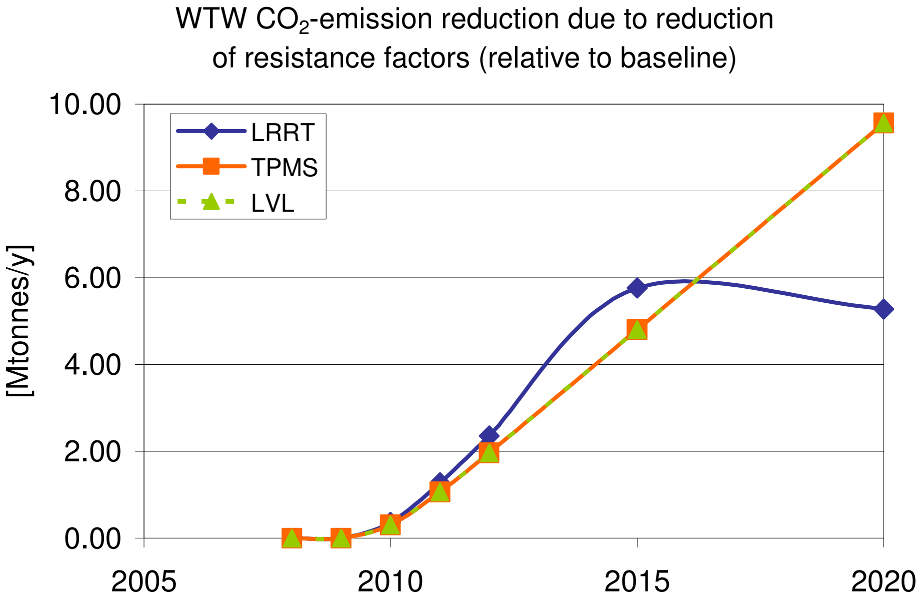


Figure 17 Annual well-to-wheel GHG emission reduction (in Mtonnes CO_2eq p.a.) for EU15 resulting from promoting the use of low rolling resistance tyres, tyre pressure monitoring systems and low viscosity lubricants. Based on "conservatively realistic" scenario as worked out in TNO (2006).

The above mentioned scenarios as used in TNO (2006) can be considered "conservatively realistic" scenarios. However, to be more in line with the approach followed in the underlying study for other options in the transport sector and other sectors, alternative scenarios have been constructed that could be called “optimistically realistic”, and which basically estimate the technical potential taking account of the basic dynamics determined by aspects such as the fleet renewal rate or lifetime of the product. The results for this scenario are depicted in Figure 18.

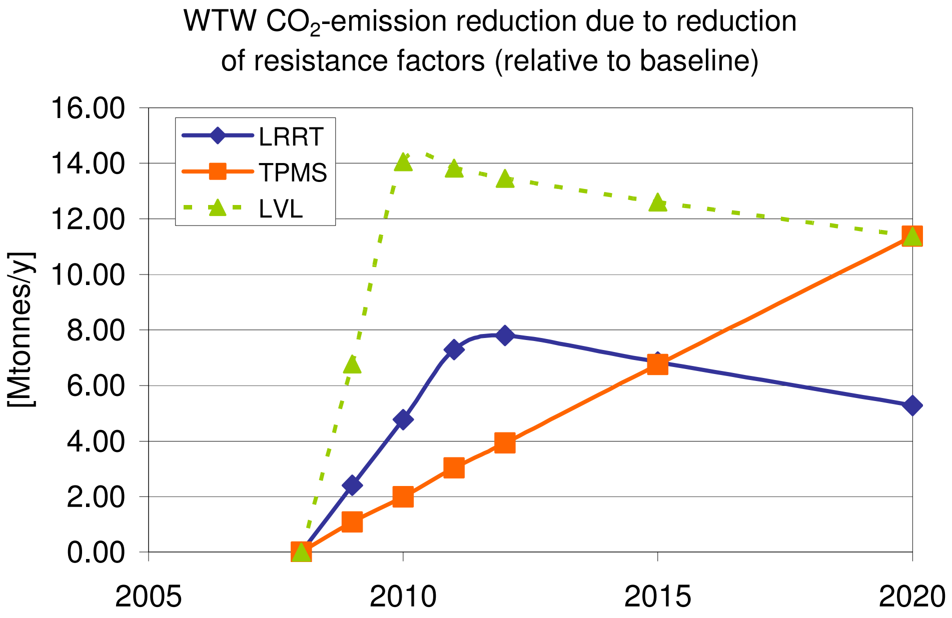


Figure 18 Annual well-to-wheel GHG emission reduction (in Mtonnes CO_{2eq}/a) for EU15 resulting from promoting the use of low rolling resistance tyres, tyre pressure monitoring systems and low viscosity lubricants. Based on “optimistically realistic” scenario defined to be consistent with approach for analysis of other options in this study.

5.1.7. APPLICATION OF CNG

CO_2 abatement costs

Based on an evaluation of data from various sources TNO (2006) has derived the data depicted in Table 23 for the additional costs and direct (tank-to-wheel or TTW) GHG reduction of natural gas vehicles compared to equivalent petrol vehicles in different classes. The associated well-to-wheel GHG reduction is calculated on the basis of data derived from Concawe (2006), which are displayed in Table 24. As the EU is a net importer of natural gas it is assumed that the additional natural gas used for NGVs is imported and has its origin in sources that require transport over distances of on average some 4000 km.

	NGVs compared to petrol vehicles		
	small	medium	large
add. manufacturer cost [€]	1450	1750	2050
add. retail price [€]	2090	2520	2950
TTW CO_2-reduction	22%	22%	22%

Table 23 Data for additional manufacturer costs, additional retail price and relative TTW CO_2 reduction for NGVs compared to equivalent petrol vehicles used for the assessment of CO_2 abatement costs.

	TTW		WTT	WTW	
	CO_2-emissions [gCO_2/km]		WTT CO_2-emission [gCO_2/gCO_2_TTW]	WTW CO_2-emission [gCO_2/km]	
petrol	148.0	100%	0.170	173.2	100%
diesel	125.8	85%	0.195	150.3	87%
CNG EU-mix	115.4	78%	0.149	132.7	77%
CNG 4000 km	115.4	78%	0.249	144.2	83%
CNG 7000 km	115.4	78%	0.386	160.0	92%

Table 24 Calculation of WTW CO_2 emissions of NGVs

In calculating the abatement costs assumptions have to be made on whether NGVs replace e.g. only petrol vehicles or both petrol and diesel vehicles. The results for the latter case are presented in Table 25. Other comparisons are also possible, leading to slightly different but overall quite similar MAC-values. The relation between the costs of petrol/diesel and the costs of natural gas as shown in this table have been derived by means of linear interpolation of data for the 25 €/bbl and 50 €/bbl scenarios as given by Concawe (2006).

		average, M 2008-base	NGV EU-mix	NGV 4000km	NGV 7000km	gas cost [€/m^3]	petrol cost [€/l]
TTW CO_2-reduction	[%]		20.1%	20.1%	20.1%		
NEDC CO_2-emission	[g/km]	145	115	115	115		
real-world CO_2-emission	[g/km]	173	138	138	138		
WTW CO_2-emission	[g/km]	204	159	172	191		
WTW CO_2-reduction	[%]		22.4%	15.6%	6.4%		
add. ret. price minus tax	[€/veh]	0	1450	1450	1450		
CO_2 abatement costs	[€/tonne]	--	243	347	852	0.32	0.21
	[€/tonne]		218	312	765	0.40	0.30
	[€/tonne]		187	268	658	0.49	0.41
	[€/tonne]		135	193	473	0.65	0.60

Table 25 Comparison of the abatement costs for reaching a CO_2 emission reduction compared to an average medium sized 2008 average baseline vehicle (50% petrol / 50% diesel) by means of NGVs, for oil prices varying from 25, 36, 50 to 74 €/bbl and petrol/diesel and natural gas costs varying accordingly.

CO_2 reduction potential for EU15

The total CO_2 reduction potential (in Mtonnes in a given year or total over a given period) can not be estimated in a simple way, as it depends on the share of NGVs that is assumed in the new vehicle sales in the time period under consideration.

In general the market penetration of NGVs will depend on the type, target and effectiveness of policies employed to stimulate the use of NGVs. The penetration rate will most dominantly be determined by the speed with which new fuel infrastructure can be set up. The effectiveness of policies influencing the costs of NGVs relative to petrol and diesel vehicles can be assessed in TREMOVE. This would require assumptions on e.g. the levels of tax or subsidy on vehicles and fuel. In TNO (2006) only a back-of-the-envelope calculation is given of the total CO_2 reduction potential that can be achieved at different levels of assumed market penetration.

For estimating the overall reduction potential for NGVs two scenarios are assumed for the additional use of NGVs compared to the TREMOVE baseline. In both scenarios NGVs are assumed to replace 10% of the total sales of new conventional vehicles on petrol and diesel in 2012 and beyond. Policies to promote the use of NGVs are assumed to be implemented from 2008 onwards. A linear increase of this (additional) share[31] is assumed from 0% in 2007 to 10% in 2012. In scenario 1 NGVs are assumed to replace only petrol vehicles, while in scenario 2 NGVs are assumed to replace 10% of new petrol vehicle sales and 10% of new diesel vehicle sales.

Starting point for the calculations is the TREMOVE 2.42 baseline for EU15. The real-world Tank-to-Wheel CO_2 emissions of NGVs have been calculated from the baseline values in the TREMOVE 2.42 baseline using the emission reduction percentage as given in Table 23. Calculations of the overall reduction also include well-to-tank emissions based on Concawe (2006) as given in Table 24. It should be noted here that the petrol / diesel shares in the TREMOVE 2.42 baseline are inconsistent with data as used in TNO (2006). In TNO (2006) a 50% / 50% share of petrol / diesel is assumed in the 2008 new vehicle sales and 45% / 55% in 2012. In TREMOVE 2.42 the petrol/diesel share is around 66% / 33% in 2008 and thereafter.

---

[31] Relative to the small share of NGVs in the baseline as a result of autonomous market trends or existing national policies.

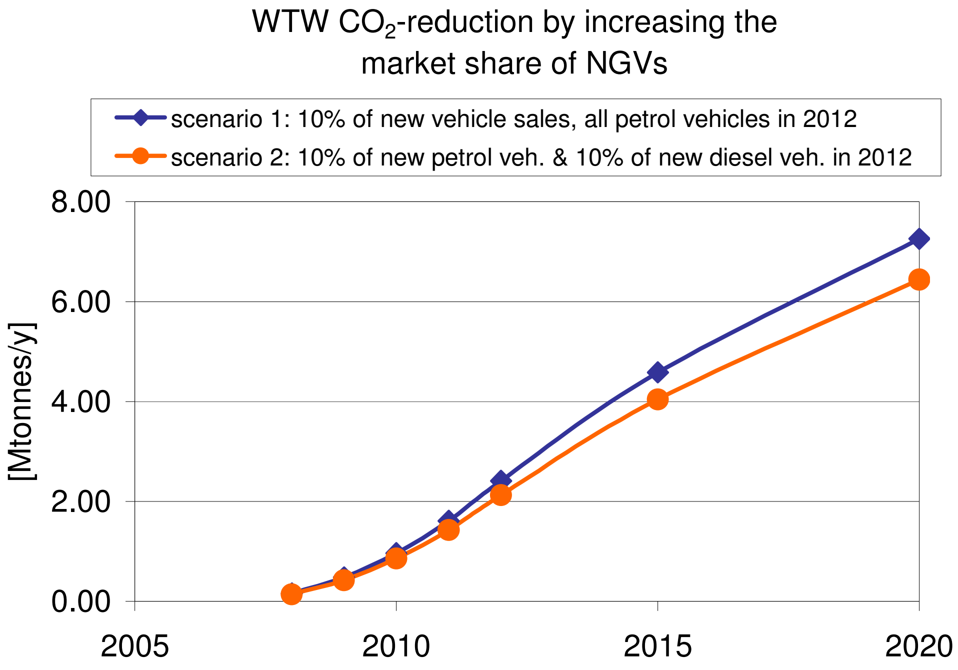


Figure 19 Total annual well-to-wheel GHG emission reduction (in Mtonnes CO_{2eq}/a) for EU15 which can be reached by an additional share of NGVs in new vehicles sales (compared to baseline) ranging from 2% in 2008 to 10% in 2012 and beyond.

The resulting overall GHG emission reduction for EU15 is presented in Figure 19. Due to the relatively low share of diesel vehicles in the TREMOVE 2.42 baseline the difference between scenario 1 and scenario 2 is rather limited. Similar to the case of technical measures applied to petrol and diesel vehicles as presented in section 0, the overall reduction resulting from increasing the share of NGVs in new vehicle sales between 2008 and 2012 still increases after 2012 as the share of NGVs in the fleet is still increasing after 2012.

5.1.8. INCREASED APPLICATION OF BIOFUELS

TNO (2006) only considers 1st generation biofuels blended into petrol and diesel and only looks at increased application in passenger cars. For petrol the costs and well-to-wheel (WTW) CO_2 reduction of 1st generation ethanol from production within the EU or in Brasil are assessed. For diesel only 1st generation biodiesel from production in the EU is considered. This study uses the same assumptions with regard to the fuels, but also assesses the application in light-duty commercial vehicles (N_1-vehicles).

For the case of passenger cars abatement costs and reduction potential are calculated for the situation in which 50% of all biofuel consumed is ethanol and 50% is biodiesel. In N_1-vehicles the share of diesel vehicles is higher. For this application only 35% of all biofuel used is assumed to be ethanol, while 65% is biodiesel. For both applications half of the consumed ethanol is assumed to be produced in the EU while the other half is assumed to be imported from Brasil.

CO_2 abatement costs

In TNO (2006) various information sources are compared for the assessment of CO_2 abatement costs associated with the use of 1st generation biofuels blended in conventional petrol and diesel. The estimates for WTW CO_2 reduction and production cost, as used in the analysis, are presented in Table 26 and Table 27. Results of this assessment are depicted in Figure 20. For each of the fuels this graph shows a central estimate as well as two extremes determined by the spread in cost and WTW CO_2 reduction values as found in literature and depicted in Table 26 and Table 27. In the calculations underlying this graph it is assumed that the price of imported ethanol is a commodity price, determined by production costs in the case of low oil prices but closely following the oil price when it is higher than the production costs of ethanol.

Fuel	High	Central	Low
Brazilian sugarcane or lignocellulosic bioethanol	90	80	70
European bioethanol	60	50	40
Biodiesel	60	50	40
BTL	95	85	75

Table 26 Indicative Percentage WTW reductions in CO_2eq for a range of Biofuels

Fuel	High	Central	Low
Brazilian sugarcane bioethanol	14	12	10
European bioethanol	25	19	13
Biodiesel	22	18	15

Table 27 Indicative production costs in €/GJ for a range of biofuels

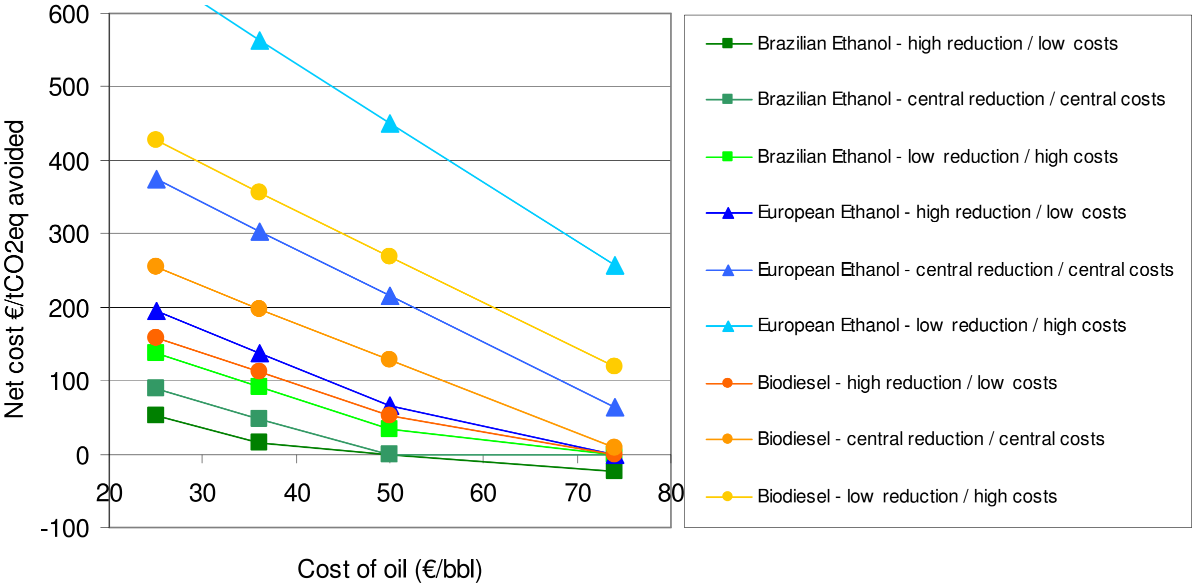


Figure 20 Cost effectiveness of biofuels as a function of oil price ('price taker' case).

For the assessment presented here only the central estimates are used. Based on the share of the various EU-produced and imported biofuels (as discussed in the introduction above), their individual abatement cost values and their WTW CO_2 reduction percentage the average abatement costs have been calculated for the various oil price levels. The results are presented in Table 28.

	CO_2-abatement costs [€/tonne]			
oil price [€/bbl]	**25**	**36**	**50**	**74**
M1-vehicles (25% Brasilian ethanol, 25% EU ethanol, 50% EU biodiesel)	223	169	103	17
N1-vehicles (17.5% Brasilian ethanol, 17.5% EU ethanol, 65% EU biodiesel)	232	177	110	15

Table 28 Average CO_2 abatement costs for application of a mix of 1st generation biofuels in passenger cars and vans.

CO_2 reduction potential for EU15

As explained above, it is assumed that for the given market share the costs (and consequently the CO_2 abatement costs) do not depend on the market share or blending percentage. The CO_2 reduction potential, however, is fully dependent on the amount of additional biofuel use that is assumed in the period until 2012. In TNO (2006) a reduction potential of around 3.5 Mtonnes/a is calculated per 1% additional use of biofuels (as share of total fuel consumption).

For the purpose of this study again an "optimistically realistic" approach is used, which basically estimates the technical potential taking account of the basic dynamics determined by technical boundaries. As a baseline it is assumed that the 2010 target of 5.75%, as set by the Biofuels Directive, is met. For the period after 2010 it is assumed that this percentage is immediately increased to 10%, resulting in an average additional biofuels use of 1.7% over the 2008-2012 period. Both vehicle technology and fuel distribution infrastructure allow an instantaneous increase to this level. The main practical limitation to reaching this would be the availability of biofuels from production inside or outside the EU. Based on TREMOVE data an average reduction potential over the 2008-2012 period of 6 Mtonnes/a is estimated for EU15.

5.1.9. FUEL EFFICIENT DRIVING

The fuel consumption of a car is influenced by the driving behaviour of the driver to a significant extent. Fuel consumption can be significantly reduced by means of a fuel efficient driving style, also referred to as eco-driving. Fuel efficient driving is achieved by:

- Operating the engine in its most efficient range, i.e. in an area of the engine map (of torque and engine speed) where the fuel efficiency is highest, and example of an efficiency map is given in the picture below;
- Reducing the waste of kinetic energy by unnecessary braking and using the benefit of fuel cut off;
- Avoiding unnecessary energy demand by:
  - avoiding unnecessary (too strong) accelerations;
  - avoiding high speeds;
  - minimizing the use of auxiliary equipment;
  - minimizing driving resistance (tyre pressure).

In essence this comes down to:

- Reducing the energy needed at the wheels by influencing the driving pattern (v(t));
- Optimising the efficiency with which the engine delivers it's energy to the wheels by reducing the amount of part or low load operation of the engine.

These rather physical explanations have been translated in more practicable and generally understandable tips, suitable for campaigns and driving courses, as for example in the Netherlands:

- Shift up as soon as possible at a maximum of 2500 rpm (for diesel a maximum of 2000 rpm) to a gear as high as possible;
- Press the throttle quickly and vigorously just as much so that you can keep up with the traffic;
- Do not shift down to a lower gear too early, and keep the car rolling without disengaging the clutch and in a gear as high as possible;
- Keep the speed as steady as possible, drive at low engine speeds in the highest gear as possible;
- Look ahead as much as possible and anticipate other traffic.

Depending on their driving style, drivers may save between 5 and 25% fuel directly after having received instructions or lessons. The average reduction in practice is more of the order of 5-10% and tends to reduce over time.

TNO (2006) concludes that the assessment of the CO_2 abatement costs of eco-driving is extremely sensitive to the methodology that is used and to variations in the values of the input parameters The initial effect of eco-driving is reasonably well measured and documented. The long term effect on the other hand is less well known, but is expected to be significantly smaller. As both the level of effect and the duration strongly affect the outcome of the CO_2 abatement cost calculation the assessment presented here has significant uncertainty margins.

The effective use of a gear shift indicators (GSI) in itself only captures part of the total reduction potential of eco-driving. On the other hand GSI can be an effective tool to assist drivers in maintaining a correct and effective fuel efficient driving style. In this way the use of GSI in combination with eco-driving is expected to increase the long-term effectiveness of eco-driving.

In TNO (2006) it is assumed that the long term effect of applying eco-driving is a fuel consumption reduction of 3%. With the aid of GSI this can be improved to 4.5%. The effect of only using GSI is 1.5%. The duration of the effect of eco-driving is assumed to be 40 years for new drivers to whom ecodriving has been taught during the regular driver training for their drivers licence. For existing drivers, e.g. following a dedicate course on eco-driving, an average duration of the effect of 25 years is assumed. The costs of lessons to existing drivers are set at €100, while inclusion of eco-driving in training of new drivers involves no additional costs. The additional manufacturer costs of GSI are €15 (€22 additional retail price), with a lifetime equal to the lifetime of the vehicle.

CO_2 abatement costs

The costs, CO_2 reduction and resulting abatement costs for eco-driving depend on the use and cost of eco-driving training and the use and cost of GSI. In principle different combinations are possible. For the purpose of this study a scenario has been constructed in which eco-driving is introduced by four different routes:

- eco-driving taught to new drivers as part of the training for their drivers license, and who afterwards apply it in a car without GSI; the number of new drivers licenses per year is about 2.5% of the total population with drivers license so that this option has a penetration rate of 2.5% p.a.;
- existing drivers who voluntarily follow an eco-driving course and apply it in a car without GSI; It is assumed that after 2008 each year 1.5% of all existing drivers follow a course;
- existing drivers who are offered an eco-driving course when they buy a new car with GSI (application of GSI assumed to be obliged on all new cars after 2008); the yearly sales of new

cars is about 8% of the total fleet. It is assumed that half of the new car buyers makes use of the offer, so that this option has a penetration rate of 4% p.a.;

- drivers who are offered an eco-driving course when their company leases a new car with GSI (application of GSI assumed to be obliged on all new cars after 2008); It is assumed that this option has a penetration rate of 4% p.a.

For each of these (and several other) options CO_2 abatement costs have been calculated in TNO (2006). The results are summarised in Table 29. Average abatement costs for the combination of these four options into one scenario can be derived on the basis of a weighted average over the reduction potentials of the individual options (see also section 5.1.9).

	reduction potential 2008-2012 [Mtonne/y]	CO_2-abatement costs [€/tonne]			
oil price [€/bbl]		**25**	**36**	**50**	**74**
new drivers	0.90	-35	-50	-69	-100
existing drivers with training	0.54	-2	-21	-45	-85
new cars with GSI + training	2.17	-7	-26	-49	-89
lease drivers with GSI + training	0.54	-7	-26	-49	-89
total reduction	4.15				
average abatement costs		**-13**	**-31**	**-53**	**-91**

Table 29 Average CO_2 abatement costs of ecodriving for a scenario in which ecodriving is implemented through four different routes (see text).

CO_2 reduction potential for EU15

An estimation of the annual CO_2 reduction potentials for EU15 of the four introduction routes as sketched above is presented in Figure 21. Average values for the 2008-2012 period are also included in Table 29.

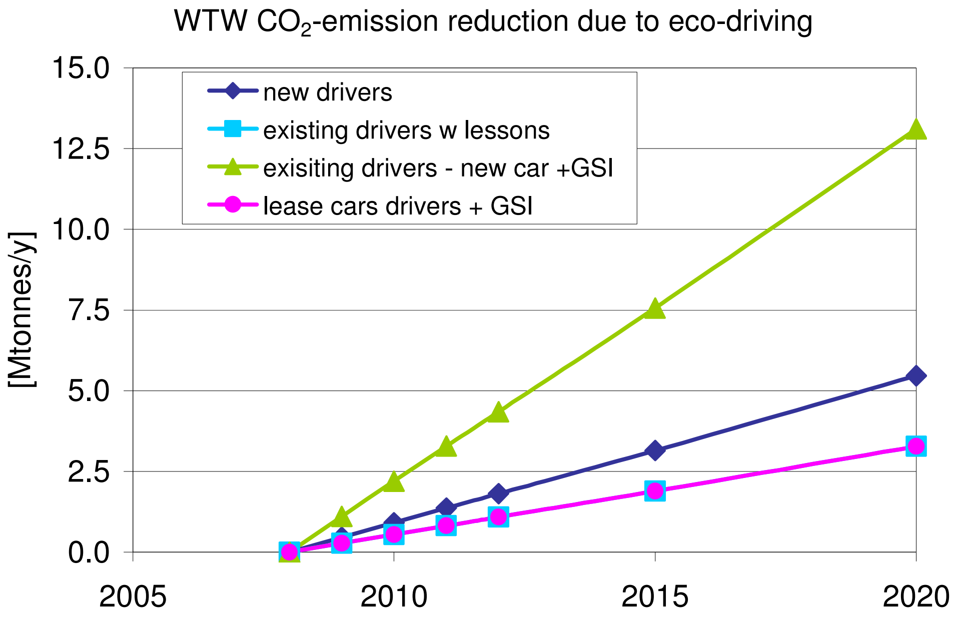


Figure 21 Annual Well-to-Wheel GHG emission reduction (in Mtonnes CO_{2eq}/a) for EU15 resulting from eco-driving applied to passenger cars based on 4 different routes for implementing eco-driving (see text).

5.1.10. TECHNICAL OPTIONS TO REDUCE FUEL CONSUMPTION OF N_1 VEHICLES

Many of the technologies described in section 0 on passenger cars can also be used to reduce CO_2 emissions from light-duty commercial vehicles (N_1-vehicles / vans). In the context of reviewing the existing EU-policy on CO_2 reduction in the transport sector and impact assessment of possible new policy measures also CO_2 reduction in N_1-vehicles is considered. This could be done in various ways, e.g. by including N_1-vehicles in the voluntary agreements with the automotive industry, by regulating CO_2 emissions from N_1-vehicles, or by including N_1-vehicles in targets set at the level of manufacturers or holding companies with respect to the sales averaged CO_2 emission of new vehicles as measured on the type approval test. Due to the fact that N_1-vehicles so far have not been subject to CO_2 policy the first steps in reducing CO_2 emissions from this vehicle class may even be more cost-effective than further improvements of the CO_2 emissions of passenger cars beyond the 2008/9 target. In TNO (2006) therefore also an assessment is made of the costs and impacts of applying CO_2-reducing measures to N_1-vehicles.

CO_2 abatement costs

For the assessment of the costs of CO_2 reduction in N_1-vehicles a simplified approach has been developed which is based on the methodology and data as used for passenger cars. This method is an update of the approach used in an earlier assessment (TNO 2004a). Also in this approach continuous cost curves are constructed which can be applied to 2002 baseline vehicles for the various segments (Class I, II and II vehicles on petrol and diesel). On the basis of these cost curves then the most cost effective way of realising a certain average CO_2 reduction value per vehicle can be assessed. An overview of the results for four different levels of emission reduction is displayed in Table 30. Results have been derived under the following assumptions:

- 2012 sales distributions over the various segments are taken from vehicle stock sheets underlying (TNO 2004b);
- Fuel consumption benefits and CO_2 reductions are calculated for real-world figures, using the same factor of 1.195 as for M_1-vehicles to translate TA data as determined in the assessment to RW data;
- Lifetime CO_2 emissions are further corrected to WTW greenhouse emission using a WTW/WTT factor of 1.186 based on a sales weighted average of the WTW/WTT factors for the petrol and diesel energy chain as presented in Table 16;
- Annual mileage data are taken from (TNO 2004b) and correspond to:
  - 19336 km/a for petrol vehicles
  - 23579 km/a for diesel vehicles
  - 21993 km/a for average vehicles based on a sales weighted average;
- Average vehicle lifetime is assumed to be 15 years, based on data from (TNO 2004b).

				Class I		Class II		Class III		average	abatement costs [€/tonne]			
				petrol	diesel	petrol	diesel	petrol	diesel		0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
	2002 new vehicle sales			9%	19%	10%	23%	12%	27%					
	2008 new vehicle sales			10%	18%	12%	21%	14%	25%					
	2012 new vehicle sales			10%	17%	12%	21%	15%	25%					
	2002 baseline CO2-emission		[g/km]	179	160	184	175	283	227	200.9				
	2012 baseline CO2-emission		[g/km]	171	152	174	163	265	209	189.7				
least costs - 2012	15 g/km reduction	ΔCO2	[g/km]	22.3	7.6	20.2	7.9	32.3	10.1	15.0	6	-16	-44	-91
		CO2	[g/km]	149	144	154	155	232	199	175				
		Δcosts	[€]	613	164	581	189	717	179	352				
	30 g/km reduction	ΔCO2	[g/km]	43.0	16.6	40.2	18.3	60.6	20.3	30.0	63	41	14	-34
		CO2	[g/km]	128	135	134	145	204	189	160				
		Δcosts	[€]	2027	798	1945	926	2675	898	1394				
	45 g/km reduction	ΔCO2	[g/km]	60.0	27.4	56.5	30.8	86.5	32.4	45.0	131	108	81	34
		CO2	[g/km]	111	124	118	132	178	177	145				
		Δcosts	[€]	4192	2178	4011	2530	5977	2463	3315				
	60 g/km reduction	ΔCO2	[g/km]	74.9	39.2	70.7	44.6	110.2	45.9	60.0	206	184	156	109
		CO2	[g/km]	96	112	103	118	155	163	130				
		Δcosts	[€]	7090	4498	6769	5226	10573	5093	6239				

Table 30 Average costs per vehicle and CO_2 abatement costs for CO_2 reduction by technical measures applied to vans.

CO_2 reduction potential for EU15

Similar to the case of passenger cars in section 0, also for N_1-vehicles a first indication of the overall reduction potential in Mtonnes/a for the EU15 is assessed using a vehicle stock spreadsheet containing time series of data on the number of vehicles of different years of construction in the fleet, their CO_2 emission and their annual mileage. This spreadsheet is based on output from the TREMOVE 2.42 baseline. The overall reduction will evolve over time and is calculated for the period 2002 to 2020.

The annual well-to-wheel GHG emission reduction (in Mtonnes CO_{2eq}/a) resulting from technical measures applied to N_1-vehicles is displayed in Figure 22 Results are presented for four scenarios representing different levels in the average reduction of CO_2 emissions on the Type Approval test (resp. 15, 30, 45 and 60 g/km) of new vehicles sold in 2012 compared to the baseline situation in 2002. It is assumed that policies aiming at achieving these reductions are entering into force in 2008. As a consequence the CO_2 emission figures between 2002 and 2008 are kept the same as in the TREMOVE 2.42 baseline. Type Approval values for intermediate years between 2009 and 2012 have been determined by means of linear interpolation. After 2012 the Type Approval CO_2 emission of new vehicles is assumed to remain constant at the 2012 level. Real-world CO_2 emissions in the policy scenarios for the different reduction levels have been determined using scaling factors based on the development of Type Approval values between 2008 and 2012 which are applied to the real-world CO_2 emission factors as included in the TREMOVE baseline data. Calculations of the overall reduction include well-to-tank emissions based on Concawe (2006).

As can be seen from Figure 22 the overall reduction resulting from measures taken between 2008 and 2012 still increase after 2012 as the share of vehicles meeting the 2012 target in the fleet is still increasing after 2012. For the 15 g/km reduction target a decrease is visible after 2015. This is caused by the fact that the TREMOVE baseline includes some autonomous efficiency improvements between 2009 and 2020, while in the policy scenarios emissions of new vehicles are assumed constant after 2012. The motivation for the latter is that technical options that may be used in the autonomous developments assumed in the TREMOVE baseline scenario are used earlier in the policy scenario for reaching the 2012 target.

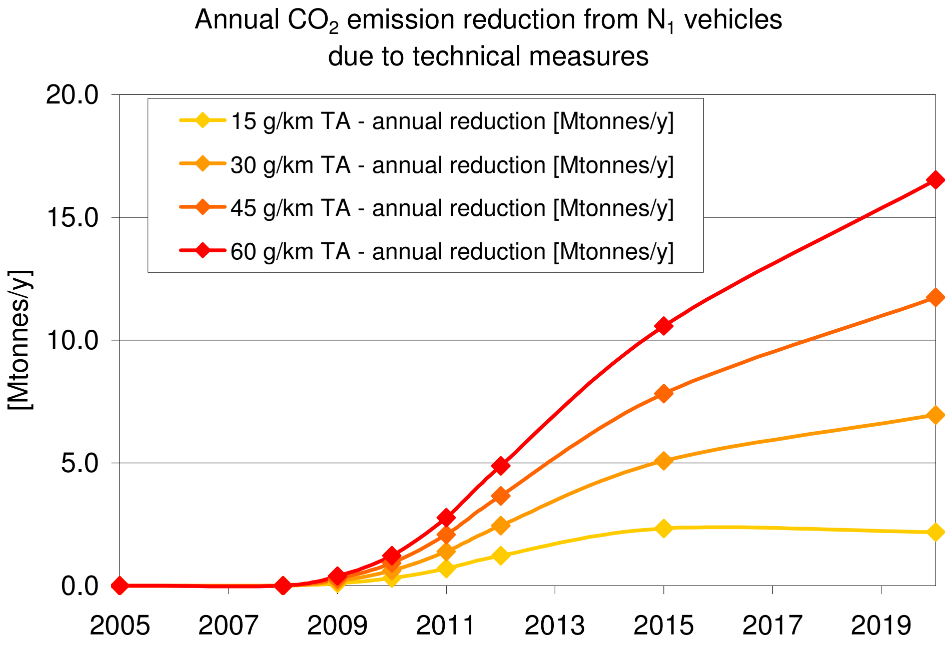


Figure 22 Annual well-to-wheel GHG emission reduction (in Mtonnes CO_{2eq}/a) for EU15 resulting from technical measures applied to light duty commercial vehicles (N1-vehicles) in order to reach an average 2012 Type Approval CO2 emission value which is 15, 30, 45 or 60 g/km lower than the average for 2002.

5.1.11. RESULTING MAC CURVES

The above data on CO_2 abatement costs and reduction potentials for the individual options can be combined into overall MAC-curves for passenger cars and vans. To be consistent with the methodology as set out in chapter 2, the information presented in the above sections on CO_2 reduction potentials per year in EU15 based on TREMOVE data has been translated into annual CO_2 reduction potentials in EU25 based on PRIMES data by applying the translation factor as described in section 5.1.2. Furthermore data for individual years have been aggregated to average CO_2 reduction potentials for the 2008-2012 period by averaging annual values over this 5 year period. The resulting cost curve for the passenger cars sector is displayed in Figure 23. Exact values for the different options are presented in Table 31. The cost curves and corresponding data per option for N_1-vehicles are displayed in Figure 24 resp. Table 32.

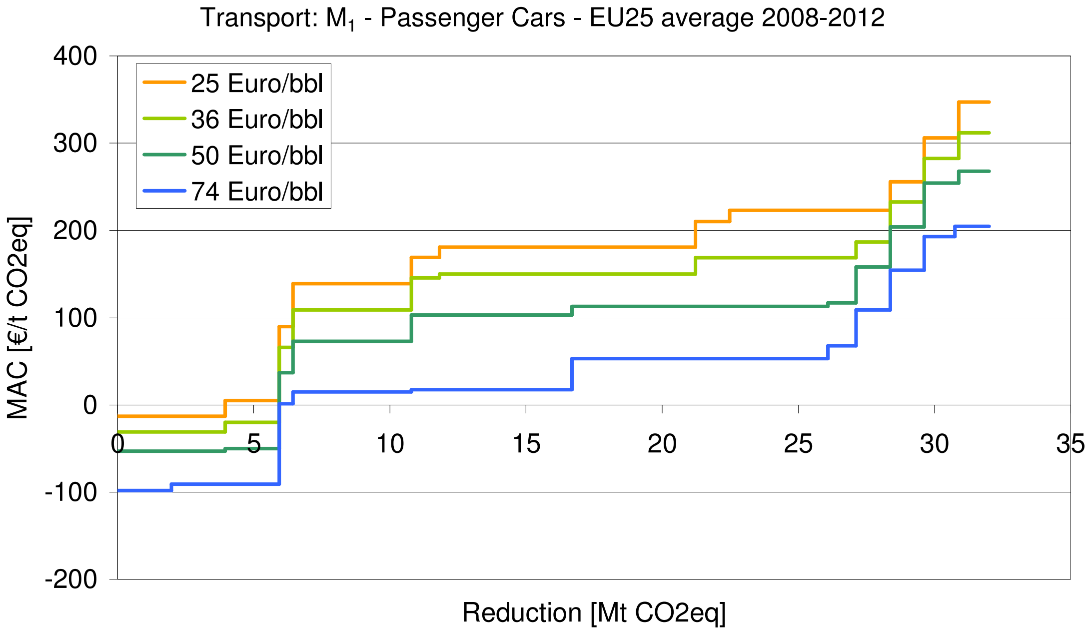


Figure 23 MAC curves for passenger cars. Reduction potentials are estimated as average reductions in the period 2008-2012 in the EU25.

	Passenger cars			
Oil price [€/bbl]	Reduction options	Reduction potential [Mtonne/y]	Cumulative reduction [Mtonne/y]	Abatement costs [€/tonne]
25	Fuel efficient driving	4.0	4.0	-13
	Tyre pressure monitoring systems	2.0	5.9	5
	Fuel efficient airco systems	0.5	6.4	90
	Low rolling resistance tyres	4.4	10.8	139
	Reduction of average TA CO2 emission from 140 to 135 g/km	1.0	11.8	169
	Low viscosity lubricants	9.4	21.2	181
	Reduction of average TA CO2 emission from 135 to 130 g/km	1.3	22.5	210
	Biofuels (1,7% additional use)	5.9	28.4	223
	Reduction of average TA CO2 emission from 130 to 125 g/km	1.3	29.6	256
	Reduction of average TA CO2 emission from 125 to 120 g/km	1.3	30.9	306
	CNG	1.1	32.0	347
36	Fuel efficient driving	4.0	4.0	-31
	Tyre pressure monitoring systems	2.0	5.9	-20
	Fuel efficient airco systems	0.5	6.4	66
	Low rolling resistance tyres	4.4	10.8	109
	Reduction of average TA CO2 emission from 140 to 135 g/km	1.0	11.8	146
	Low viscosity lubricants	9.4	21.2	150
	Biofuels (1,7% additional use)	5.9	27.1	169
	Reduction of average TA CO2 emission from 135 to 130 g/km	1.3	28.4	187
	Reduction of average TA CO2 emission from 130 to 125 g/km	1.3	29.6	233
	Reduction of average TA CO2 emission from 125 to 120 g/km	1.3	30.9	283
	CNG	1.1	32.0	312
50	Fuel efficient driving	4.0	4.0	-53
	Tyre pressure monitoring systems	2.0	5.9	-50
	Fuel efficient airco systems	0.5	6.4	37
	Low rolling resistance tyres	4.4	10.8	73
	Biofuels (1,7% additional use)	5.9	16.7	103
	Low viscosity lubricants	9.4	26.1	113
	Reduction of average TA CO2 emission from 140 to 135 g/km	1.0	27.1	117
	Reduction of average TA CO2 emission from 135 to 130 g/km	1.3	28.4	158
	Reduction of average TA CO2 emission from 130 to 125 g/km	1.3	29.6	204
	Reduction of average TA CO2 emission from 125 to 120 g/km	1.3	30.9	254
	CNG	1.1	32.0	268
74	Tyre pressure monitoring systems	2.0	2.0	-98
	Fuel efficient driving	4.0	5.9	-91
	Fuel efficient airco systems	0.5	6.4	2
	Low rolling resistance tyres	4.4	10.8	15
	Biofuels (1,7% additional use)	5.9	16.7	17
	Low viscosity lubricants	9.4	26.1	53
	Reduction of average TA CO2 emission from 140 to 135 g/km	1.0	27.1	68
	Reduction of average TA CO2 emission from 135 to 130 g/km	1.3	28.4	109
	Reduction of average TA CO2 emission from 130 to 125 g/km	1.3	29.6	155
	CNG	1.1	30.7	193
	Reduction of average TA CO2 emission from 125 to 120 g/km	1.3	32.0	205

Table 31 MAC values and reduction potentials for passenger cars. Reduction potentials are estimated as average reductions in the period 2008-2012 in the EU25.

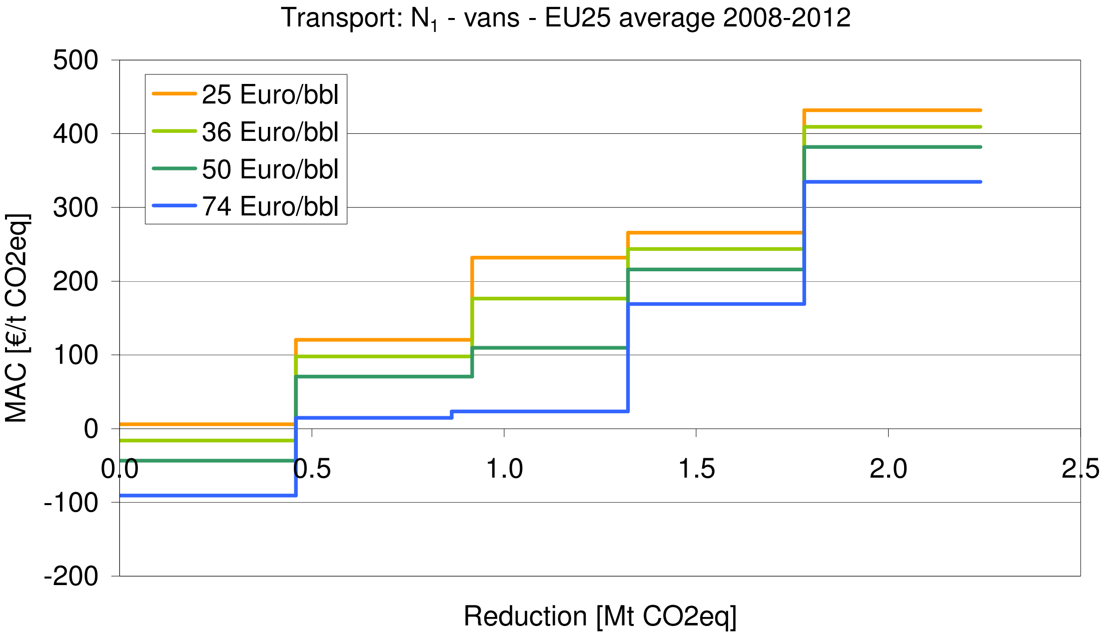


Figure 24 MAC curves for vans. Reduction potentials are estimated as average reductions in the period 2008-2012 in the EU25.

Oil price [€/bbl]	*Vans* Reduction options	Reduction potential [Mtonne/y]	Cumulative reduction [Mtonne/y]	Abatement costs [€/tonne]
25	Reduction of average TA CO2 emission by 15 g/km	0.5	0.5	6
	Reduction of average TA CO2 emission by 30 g/km	0.5	0.9	120
	Biofuels (1% additional use)	0.4	1.3	232
	Reduction of average TA CO2 emission by 45 g/km	0.5	1.8	266
	Reduction of average TA CO2 emission by 60 g/km	0.5	2.2	432
36	Reduction of average TA CO2 emission by 15 g/km	0.5	0.5	-16
	Reduction of average TA CO2 emission by 30 g/km	0.5	0.9	98
	Biofuels (1% additional use)	0.4	1.3	177
	Reduction of average TA CO2 emission by 45 g/km	0.5	1.8	243
	Reduction of average TA CO2 emission by 60 g/km	0.5	2.2	409
50	Reduction of average TA CO2 emission by 15 g/km	0.5	0.5	-44
	Reduction of average TA CO2 emission by 30 g/km	0.5	0.9	71
	Biofuels (1% additional use)	0.4	1.3	110
	Reduction of average TA CO2 emission by 45 g/km	0.5	1.8	216
	Reduction of average TA CO2 emission by 60 g/km	0.5	2.2	382
74	Reduction of average TA CO2 emission by 15 g/km	0.5	0.5	-91
	Biofuels (1% additional use)	0.4	0.9	15
	Reduction of average TA CO2 emission by 30 g/km	0.5	1.3	23
	Reduction of average TA CO2 emission by 45 g/km	0.5	1.8	169
	Reduction of average TA CO2 emission by 60 g/km	0.5	2.2	335

Table 32 MAC values and reduction potentials for vans. Reduction potentials are estimated as average reductions in the period 2008-2012 in the EU25.

5.1.12. COMPARISON OF RESULTS FROM TASK A (TNO 2006) AND TASK B (ZEW 2006)

Introduction

During 2005 and 2006 two studies have been carried out in support of the Impact Assessment, to be prepared by the European Commission in the preparation of a new strategy aimed at reducing the CO_2-emissions of light-duty vehicles to a level of 120 g/km in 2012:

Task A (TNO 2006) is called "Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars" (contract nr. SI2.408212) which has been carried out by TNO, IEEP and LAT on behalf of the DG-ENTR. Task A has reviewed the potential and related costs of various technical and non-technical options for reducing the CO_2-emissions from passenger cars beyond the results reached in 2008/2009 based on the existing Community strategy and has provided to TML and Task B for further assessments;

Task B (ZEW 2006) is the project "Service contract in support of the extended impact assessment of various policy scenarios to reduce to reduce CO_2 emissions from passenger cars" (contract nr. 070501/2004/392571/MAR/C1), carried out by ZEW and B&D Forecast. This project assesses the macro-economic impacts as well as the impacts in the automotive industry of scenarios consisting of various technical and non-technical measures which are reviewed in Task A. In addition to these two Tasks, TML is performing TREMOVE calculations to assess impacts on the transport system and the environment.

Based on runs with the TREMOVE model the report of Task B derives CO_2-abatement costs for the various measures studied in Task A, which differ strongly from the CO_2-abatement costs calculated in Task A. This section reports on efforts made to understand the differences in the results. To this end we have studied the Task B report and have had interactions with ZEW and TML. From studying the Task B report and from discussions with ZEW on the PACE-T and FORCAR models it has become clear that the main differences in results form Task A and Task B relate to TREMOVE. Further analysis of the differences in the outcomes of Task A and B with respect to CO2-abatement costs thus requires more insight in the way TREMOVE calculates costs and CO_2-emissions. From the task B report there are no indications that other data than the ones supplied by Task A have been used (except for the scenarios that explicitly use the IEEP 2004 results) or that these results have been incorporated incorrectly in the model. For further details on the results of TREMOVE-runs as presented in the Task B the report by TML on the TREMOVE runs is needed. **As the report on TREMOVE runs for Task B is not yet available it is at this point not possible to further analyse the main differences between the outcomes of Task A and Task. Further work on this topic, however, is planned**.

Conclusions from the comparison of Task A and Task B results

Task B analyses three scenarios using TREMOVE:

- Scenario 2: 120 g/km through technical measures applied to new vehicles
- Scenario 3A: 125 g/km through technical measures applied to new vehicles + accompanying measures from Integrated Approach (GSI, MAC, N1 up to 15 g/km reduction, TPMS and LRRT), assuming a 1.5% p.a. autonomous weight increase trend
- Scenario 3B: Same as 3A, but with assuming a 0.5% p.a. autonomous weight increase trend, which is caused by widespread implementation of measures influencing consumer demand (taxation and consumer information)

  NOTE: In the TREMOVE analysis the tax measure, which is assumed to promote the market shift, is not modelled so that impacts on tax revenue and “costs of public funds” are based on the tax regime in the baseline.

Task A and B use different methodologies for assessing CO_2-abatement costs. In Task A CO_2-abatement costs are assessed by comparing an average 2012-vehicle to which CO2-reducing measures are applied with a baseline average 2012-vehicle, dividing the sum of additional vehicle costs and the Net Present Value of the fuel cost savings by the lifetime CO_2-emission reduction. Using TREMOVE in Task B CO_2-abatement costs are calculated by dividing the Net Present Value of the difference in cumulated costs between two scenarios over the 2010-2020 period by the difference in cumulated CO_2-emissions between two scenarios over the 2010-2020 period. Besides vehicle and fuel costs the cumulated costs also include changes in tax revenues and changes in costs of public funds as well as other impacts (but the latter have negligible values). Full details of the methodology are not clear yet. For some issues the impact needs to be further clarified:

- For cars sold in the 2010-2020 period only part of the extra technology cost (based on the annuity of the investment costs over the vehicle lifetime) is accounted for and also only the effects on CO_2-emissions occurring before and in the year 2020 (not afterwards) are accounted for. For the vehicles sold in the 2010-2020 period this leads to somewhat lower abatement costs compared to Task A as the annuity of the additional vehicle costs is calculated irrespective of annual mileage (constant investment costs per year) while these vehicles have a higher annual mileage and thus higher CO_2-reductions during the first years of their lifetime.
- The sum of changes in vehicle and fuel based tax revenues and the "cost of public funds" involves a non-zero sum if the "effectiveness"[32] of the type of tax that replaces the changes in vehicle and fuel based tax revenues is different from the “effectiveness" of vehicle and fuel based tax. In TREMOVE for the compensating tax type a choice can be made between labour tax or a generalised tax. Though not modelled it would seem that compensation by a change in the regime for vehicle and fuel based taxes would also be a possibility. Which tax

---

[32] According to TML “effectiveness” in this case is not related to elasticities, but to the secondary effects of a tax increase or decrease on the overall economy. An increase in labour tax will have a negative effect on e.g. GDP and employment.

type is used to compensate government revenue changes, however, seems an arbitrary choice, so that the impact of this factor (through the difference in "effectiveness") is debatable. The tables included below show a comparison between Task A and Task B results based on the Tables 4.2 and 4.3 (p. 70 resp. 71) and Table 5.5 (p. 87) of (ZEW 2006). For both cases the upper table is the original table from Task B. The lower table shows the impact of excluding tax impacts and neglecting small other impacts from the calculation. The overall conclusion is that the CO$_2$-abatement costs calculated by Task B are significantly smaller than the results of Task A. Comparison of the calculations incl. and excl. tax impacts shows that tax impacts only account for a quarter of the difference in abatement costs between the two studies. The remaining difference must be entirely resulting from the differences in how changes in fixed and variable costs (increased vehicle costs and fuel cost savings) are calculated.

Calculation including tax impacts (Table 4.2 & 4.3 in Task B report)

	135 g/km	130 g/km	125 g/km	120 g/km
1. variation of utility of transport users	*4,300*	*1,315*	*-5,644*	*-17,147*
- fixed resource costs	-18,229	-42,586	-70,192	-101,779
- variable resource costs	10,458	20,754	30,923	41,055
- fixed tax	-692	-1,626	-2,697	-3,923
- variable tax	11,499	22,859	34,085	43,506
- VAT on fixed res. costs	-2,043	-4,777	-7,876	-11,070
- VAT on var. res. costs	3,391	6,734	10,037	12,810
- network costs	0	0	0	0
- other costs	0	0	0	-1
- in-vehicle time price	-84	-51	46	226
- waiting time price	-3	-5	-6	-5
- other effects	3	13	36	2,034
2. variation of costs of public funds	*-9,444*	*-18,855*	*-28,182*	*-37,529*
welfare effect (1+2)	**-5,144**	**-17,540**	**-33,826**	**-54,676**
WtW CO2-eq. (tonne)	**-103,000,000**	**-208,000,000**	**-313,000,000**	**-419,000,000**
Abatement costs (€/tonne)	49.9	84.3	108.1	130.5

Calculation exclusive of tax impacts

	135 g/km	130 g/km	125 g/km	120 g/km
1. variation of utility of transport users	*-7,771*	*-21,832*	*-39,269*	*-60,724*
- fixed resource costs	-18,229	-42,586	-70,192	-101,779
- variable resource costs	10,458	20,754	30,923	41,055
- fixed tax				
- variable tax				
- VAT on fixed res. costs				
- VAT on var. res. costs				
- network costs				
- other costs				
- in-vehicle time price				
- waiting time price				
- other effects				
2. variation of costs of public funds				
welfare effect (1+2)	**-7,771**	**-21,832**	**-39,269**	**-60,724**
WtW CO2-eq. (tonne)	**-103,000,000**	**-208,000,000**	**-313,000,000**	**-419,000,000**
Abatement costs (€/tonne)	75.4	105.0	125.5	144.9
Task A @ fuel cost 0.30 €/l (€/tonne)	**146**	**166**	**188**	**212**

Table 33 Comparison of the results of Task B and Task A for the scenarios in which a sales-weighted average CO$_2$-limit of 135. 130, 125 or 120 g/km needs to be met in 2012. The lower table presents the results that Task B would have delivered if impacts on tax revenues and other impacts would not be included in the methodology for assessing CO$_2$-abatement costs

Calculation including tax impacts (Table 5.5 in Task B report)

	Scenario 2	Scenario 3A	Scenario 3B
1. variation of utility of transport users	*-17,125*	*12,565*	*30,210*
- fixed resource costs	-98,384	-73,777	-58,394
- variable resource costs	39,434	39,046	39,150
- fixed tax	-3,882	-2,918	-2,276
- variable tax	43,662	45,581	45,603
- VAT on fixed res. costs	-11,223	-8,299	-6,545
- VAT on var. res. costs	12,988	12,872	12,889
- network costs	0	10	10
- other costs	-1	112	112
- in-vehicle time price	206	-270	-557
- waiting time price	-6	-13	-17
- other effects	81	221	235
2. variation of costs of public funds	*-35,999*	*-37,552*	*-37,426*
welfare effect (1+2)	**-53,124**	**-24,987**	**-7,216**
WtW CO2-eq. (tonne)	**-403,498,944**	**-420,583,932**	**-415,751,249**
Abatement costs (€/tonne)	131.7	59.4	17.4

Calculation exclusive of tax impacts

	Scenario 2	Scenario 3A	Scenario 3B
1. variation of utility of transport users	*-58,950*	*-34,731*	*-19,244*
- fixed resource costs	-98,384	-73,777	-58,394
- variable resource costs	39,434	39,046	39,150
- fixed tax			
- variable tax			
- VAT on fixed res. costs			
- VAT on var. res. costs			
- network costs			
- other costs			
- in-vehicle time price			
- waiting time price			
- other effects			
2. variation of costs of public funds			
welfare effect (1+2)	**-58,950**	**-34,731**	**-19,244**
WtW CO2-eq. (tonne)	**-403,498,944**	**-420,583,932**	**-415,751,249**
Abatement costs (€/tonne)	146.1	82.6	46.3

Task A @ fuel cost 0.30 €/l (€/tonne) **212**

Table 34 Results of Task B for scenarios 2, 3A and 3B and comparison of the results for scenario 2 with the results of Task A. The lower table presents the results that Task B would have delivered if impacts on tax revenues and other impacts would not be included in the methodology for assessing CO_2-abatement costs.

The oil price assumption used in Task B is presented in Table 3.16 on page 52. The value of around 37 $/bbl translates to roughly 30 €/bbl. This is in between the 25 €/bbl and the 36 €/bbl values used in Task A. As abatement costs decrease with increasing oil price in the rest of this document the Task B data will be compared with Task A data for the case of 36 €/bbl.

Table 5.1 (p.84) shows that the impacts of going to 120 g/km through technical measures (Scenario 2) on transport demand are negligible (typically < 1%). Similarly Table 5.2 (p.85) shows that the impacts of 120 g/km on vehicle sales are also very small to negligible (typically < 1.5%). The vehicle cost increase associated with reducing CO_2-emissions from 140 to 120 g/km therefore does not lead to volume effects which might reduce the overall CO_2-abatement costs as calculated by TREMOVE. Assessing the size and impact of these possible volume effects was the main reason for using the TREMOVE-model. Assuming that the results from Task A are correctly incorporated in the TREMOVE runs, the differences in abatement costs as calculated by Task A and B for scenario 2 (120 g/km) are thus completely the result of the differences in methodologies used for calculating CO_2-abatement costs. Insight in the TML-report on the TREMOVE runs and further interaction with TML is necessary to find out what the differences in methodology are that cause the differences in results.

The fact that the impact of methodological differences is so large means that also for comparing data from Task B to abatement cost data from other sectors the issue of compatibility of methodologies needs to be taken into account. In this context it should be noted that the methodology used in the Blok study seems more similar to the one used by Task A than to the one used by Task B / TREMOVE. Besides the aspect of including tax impacts it should be possible to identify the other methodological reasons that cause the difference in CO_2-abatement costs between Task A and Task B. Some possible options are:

- The main difference of course is that Task A uses a vehicle-based calculation while TREMOVE uses a fleet-based calculation.
- In the TREMOVE scenarios a gradual reduction from the 2008/9 level of 140 g/km to the 2012 level of 120 g/km is assumed. This means that in the calculations over the 2010-2020 period a significant part of the CO_2-reductions is caused by vehicles that meet a limit between 140 and 120 g/km at abatement costs which are lower than those for reaching the full 120 g/km target. This leads to lower average abatement costs over the full period. The average, however, will always be higher than the abatement costs of the cheapest option. As the abatement costs for the 120 g/km scenario (Scenario 2) are about the same as the value calculated in Task A for the 135 g/km scenario, it seems that this reason can also not explain the full difference in abatement costs between Task A and B.
- Task B calculates cost and CO_2-emission reductions for the EU-25 area. Obviously in EU-10 (the new EU-countries) the baseline does not include reaching a sales average of 140 g/km in 2008/9. Implementing 120 g/km in 2012 for the EU-10 countries thus possibly involves a relatively higher overall CO_2-emission reduction compared to the baseline of which the first part is realised at negative or small positive abatement costs. This may reduce the overall abatement costs for EU-25 compared to EU-15. The size of this possible effect, however, can not be deduced from the Task B report.
- In TREMOVE vehicle mileage is a declining function of age. In Task A mileage was assumed constant over time. As mentioned above this leads to lower abatement costs for vehicles with a lifetime going beyond 2020. This effect is enhanced by the fact that, as can be seen from Table 3.5 in (ZEW 2006), the number of vehicles increases significantly between 2000 and 2020. During the time horizon included in the Task B assessment these extra vehicles have a higher average mileage than the average vehicle in the existing fleet and avoid more tonnes of CO_2 per unit investment.
- Table 3.14 of (ZEW 2006) shows that in the segment of small vehicles the number of petrol vehicles reduces by 11.5 million while the number of diesel vehicles increases by 15 mil-

lion between 2000 and 2020. For medium/big cars the number of petrol vehicles remains roughly constant at 60-something million while the number of diesels triples to 99 million between 2000 and 2020. The assumed sales/market developments in TREMOVE and Task A are very likely not entirely consistent.

Clearly the comparison between Task A and B requires further clarification of the methodology used for assessing abatement costs in Task B. At the same time it can be firmly concluded that there is no “physical” origin for the difference in results but only a difference in accounting methodology in terms of effects that are taken into account in Task B but not in Task A. “Physical” impacts on volume as a result of price changes are clearly found to be negligible.

The results per option as presented in Table 4.7 (p. 80 of (ZEW 2006)) are very different from the results of Task A (see table below). There also is a large variation in the differences between the two results. For most options Task B results in lower abatement costs, but for some also in higher abatement costs. There should be a logical explanation for these differences, but this is not given in the Task B report. For LRRT the difference is so large that some error in the implementation of the measure in TREMOVE seems to be made.

	Task A (36 €/bbl)	**Task B**
	[€/tonne]	[€/tonne]
GSI	-50	-113.2
TPMS	-20	-75.3
N1-15g/km	-16	-63.7
LRRT	109	-30.3
MAC	48/66	18.9
N1-30g/km	41	68.9
LVL	150	81.4
N1-45g/km	108	252.0
N1-60g/km	184	356.0

Table 35 Comparison of the results of Task A and B of CO_2-reducing measures which are considered as part of the Integrated Approach.

The results in the table above are derived from subtracting the CO_2-emissions and costs of different scenarios. The assumption is that if scenario I contains measures a, b, and c and scenario II contains measures a, b, c, and d, that the difference between the scenarios can be attributed to measure d. The questions is whether the used approach of subtracting results of 2 scenarios is valid and accurate.

Concerning the calculations with PACE-T and FORCAR, the only non-negligible macroeconomic effect of reaching 130 or 120 g/km, as far as I can see from the report, is that car exports are reduced while imports increase. One can understand that exports decrease under the assumption that cars manufactured in Europe but sold outside the EU are equipped with the same CO_2-reducing options as European cars sold in Europe. On markets without CO_2-targets these cars will be relatively expensive. This however is an assumption that is not necessarily completely valid. European manufacturers might differentiate models between regions. Manufacturers from outside the EU are forced to do the same if the EU imposes a CO_2-emission limit of 120 g/km. Concerning imports, on page 114 of (ZEW 2006) it is said that cars from outside the EU become relatively cheaper and that for this reason imports increase. However, under a CO_2-legislation cars from JAMA and KAMA have to meet the same CO_2-emissions standards when sold in the EU, and are thus in principle faced with similar cost increases. One would therefore expect that imports are NOT affected by a CO_2-emission limit in the EU. Also, from the input that received by TNO from ACEA, JAMA and KAMA in the Task project these is no indication that the required CO_2-reductions could be met at lower costs by JAMA or KAMA. Assumptions on possible cost differences thus have to stem from data within the PACE-T model. E.g. in Table 6.24 (p. 131) it is suggested that in the FORCAR model it is assumed that manufacturers outside the EU can realise the required CO_2-reductions at about 1/10 of the labour costs that are involved in the EU-25. It is clear that there is a difference in labour costs between regions, but it is difficult to see why it would be so big. In any case it seems that the most significant result of the PACE-T calculations stems from assumptions or insights that have been included by Task B on top of the data supplied by Task A. It therefore seems that some more explanation on these assumptions/insights would be appropriate.

With respect to the above ZEW has indicated that in PACE-T it has been assumed that JAMA has to meet the CO_2-emission standards. In PACE-T, however, Korea is part of RoW (Rest of the World). For manufacturers from US and RoW it has been assumed that their vehicle costs remain the same (i.e. that they do not have to meet the CO_2-standards). This explains the rather large increase in imports. In the model the purchasing behaviour is assumed to be fully cost-driven. ZEW mentions that in reality the increase in imports would be smaller as real world agents do not necessarily base their car purchasing decision solely on costs.

It is thus clear that the real world impacts on imports will very likely be much smaller than the figures calculated with PACE-T, on the one hand because KAMA will be subject to CO_2-legislation in the EU and on the other hand because of not fully economic purchasing behaviour. Nevertheless his modelling result does clarify that it is important in the design of CO_2-legislation to carefully consider the role of brands not covered by ACEA, JAMA and KAMA.

In chapter 6 of the Task B report also calculations are presented for a scenario based on the IEEP 2004 data. It should be noted here that the calculations by Task A are based on a dataset that includes (updates of) the data from IEEP 2004. Furthermore Task A uses the same methodology as IEEP 2004. Task A therefore fully replaces the IEEP 2004 study. The results from IEEP 2004 are thus not an alternative data set (i.e. from an unrelated study) but instead should be considered as no longer valid. Obviously one could imagine a low cost scenario based on parameter variations within or relative to the Task A calculation as e.g. discussed in paragraphs 4.2.2. and 4.2.3 of (TNO 2006) but in any case the data used in a low cost scenario should in some way be related to / based on the Task A results and not to the IEEP 2004 data as such.

According to ZEW the choice to use IEEP 2004 data for one of the scenarios was made by DG-ENV. They only performed the assessment of impacts on the automotive sector and overall economy.

Impact of Task B results on the analysis in this study

The impact of using Task B results instead of Task A results for the comparison of cost-effectiveness of greenhouse gas reductions in various sectors (GHG-study in the Framework Service Contract No. ENTR/05/18) appears limited. Obviously the options related to passenger cars and vans will shift position on the overall cost curve for measures in all sectors. Overall, however, it can already be concluded that for most options for passenger cars and vans as studied in Task A and B the abatement costs remain above 20 €/tonne[33] so that these options do not play a role in reaching the Kyoto target for EU-25 nor EU-15.

5.2. HEAVY DUTY VEHICLE (TUG)

This chapter describes the main assumptions and boundary conditions set in the baseline scenario for the heavy duty vehicle (HDV) sector and the results for the measures analysed in the HDV sector. Heavy duty vehicles include all trucks, buses and coaches with a maximum gross vehicle weight of 3.5 tons. The baseline scenario includes already the likely future improvements and measures (e.g. EURO V and EURO VI technology).

5.2.1. BASELINE SCENARIO

For the baseline scenario the engine technology, exhaust gas limits, vehicle design and driving behaviour are defined as follows.

Engine technology

In the baseline scenario we defined the emission limits for HDV including EURO VI standards from 2012 onward. From today's point of view it seems to be very unlikely not to have more stringent NO_x emission limits after EURO V due to the existing problems in meeting the air quality targets for NO_2 as well as due to exceeding the targets given for the National Emission Ceilings (NEC) in EU-Directive 2001/81/EG. For 2012 it was assumed that a new set of test cycles (the WHDC and a Not To Exceed, NTE, regulation) for type approval is mandatory, which covers a broader range of operational conditions to ensure low NO_x emission levels in real world traffic.

---

[33] For EU-25 the gap between the Kyoto target and Scenario 1 (planned measures) is 14 Mtonnes CO_2-eq. Based on the overall cost curve presented in chapter 7 (Figure 32 of this report) this gap can be bridged with measures that have negative abatement costs. For EU-15 the gap is 160 Mtonnes, but even this can be bridged by measures costing less than 20 €/tonne, according to the GHG-study report.

			CO	HC	NO_x	PM
			[g/kWh]			
1993	EURO I	ECE R 49	4.9	1.23	9	0.4
1995	EURO II	ECE R 49	4	1.1	7	0.15
2000	EURO III	ESC	2.1	0.66	5	0.1
		(ETC)	5.45	0.78	5	0.16
2005	EURO IV	ESC	1.5	0.46	3.5	0.02
		ETC	4	0.55	3.5	0.03
2008	EURO V	ESC + ETC	1.5	0.46	2	0.02
		ETC	4	0.55	2	0.03
2012 *	EURO VI	WHTC (1)	4	0.55	0.5	0.01

* Assumption for the baseline scenario

(1) WHTC (World Heavy Duty Transient Cycle) is part of the proposed set of new test cycles (WHDC) in the GTR (Global Technical Regulation). This cycle is assumed to be applied for type approval from EURO VI onward.

Table 36 Emission limits for type approval until 2012 in EU25 assumed for the study.

The type approval limits do heavily affect the fuel economy of the engines corresponding to these limits: the lower the NO_x-limits, the lower the potential for further improvements in fuel efficiency. To meet EURO V and EURO V limits the technologies given in Table 37 to Table 39 will be involved from today's point of view.

	[%] change of fuel consumption (1)	[%] change of purchase price (2)	remarks
SCR-system + small engine adaptations	-6%	+5%	urea in magnitude of 5% of fuel consumption

~70% market share for new registered HDV in 2008 assumed

(1) % compared to EURO 3 level unit = g/ton-km change of CO_2 emissions

(2) % of the total vehicle costs

Table 37 Technology to meet EURO V with SCR.

	[%] change of fuel consumption (1)	[%] change of purchase price (2)	remarks
Diesel particulate filter (DPF or PM-catalyst), improved charging, EGR-system, high pressure injection, optimisation of the engine cooling system	+2%		

~30% market share for new registered HDV in 2008 assumed

(1) % compared to EURO 3 level unit = g/ton-km change of CO_2 emissions

(2) % of the total vehicle costs

Table 38 Technology to meet EURO V without SCR.

	[%] change of fuel consumption (1)	[%] change of purchase price (2)	remarks
Meeting 0.5 g/kWh NOx with a SCR-system, diesel particulate filter, improved charging, EGR-systems, high pressure injection, optimisation of the engine cooling system	-2%	+10%	+7% of fuel consumption urea

(1) % compared to EURO 3 level unit = g/ton-km change of CO_2 emissions

(2) % of the total vehicle costs

Table 39 Technology to meet EURO VI.

The NO_x reduction to be achieved with EURO V and EURO VI most likely will lower the technological potential to reduce fuel consumption by engine improvements until 2012 by more than 10% of the actual EURO III fuel consumption value (i.e. with EURO III NO_x emission limits and the technology defined in Table 39 the fuel efficiency could be improved by more than 10%compared to EURO III engines). However, not to reduce NO_x emissions from HDV in future seems not to be an option at all, thus EURO VI is included here in the baseline scenario.

Vehicle design

Slight improvements in air resistance values and rolling resistance values are assumed. Beside the design of the single vehicles also the composition of the whole fleet is of importance for the overall results in EU25 in terms of fuel consumption, ton kilometres performed and also for the further reduction potentials (most measures are not equally effective for all HDV categories and for all driving situations, e.g. reducing aerodynamic drag has high influence in highway driving and smaller effects in urban driving; for some vehicles improvements are more difficult than for others). Figure 25 shows the results from the model GLOBEMI (see Annex to chapter 5.2).

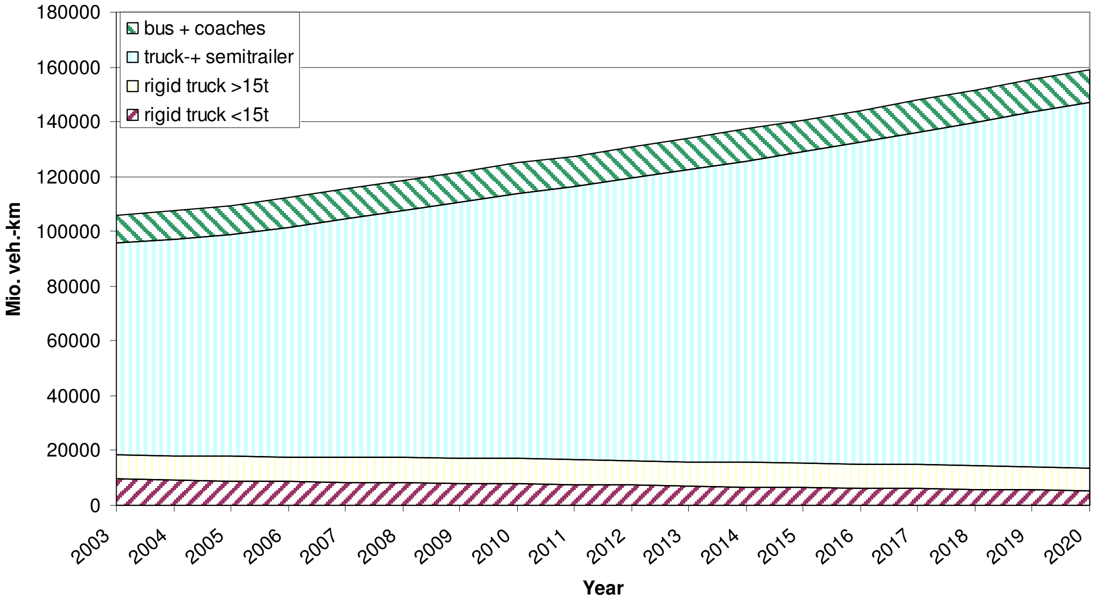


Figure 25 HD vehicle mileage assumed for EU25.

Driving style

As European average, we assume the following shares of HDV driving according to road categories:

› motorway 55%
› rural 30%
› urban 15%

From 2005 to 2020 slight increases in the share of highway driving and decreasing shares of urban driving are implemented in the model. In terms of driving styles of the drivers for given road categories no change compared to 2005 was assumed.

Costs

For the assessment of the abatement costs the basic HDV and specific costs were defined as as the retail price excluding taxes (Table 41). The CO_2 emissions were calculated from the fuel consumption, with an average density for diesel of 0.835 kg/litre and 3.14 kg CO_2 per kg fuel used. Thus the CO_2 emissions are:

$$CO_2[kg] = km_{overLifetime} \times \frac{litre_{Diesel}}{km} \times 0.835 \times 3.14$$

vehicle costs	€ 100 000 [€]
km over lifetime	1 000 000 [km]
specific fuel consumption	28 l/100 [km]
total diesel consumption over vehicle life	280 000 [l]
costs of diesel without taxes	0.3 [€/Liter]
total costs for diesel over vehicle life	84 000 [€]
total CO_2 emissions over vehicle life	734132 [kg]

Table 40 Costs, fuel consumption and CO2 emissions over the life time of the average HDV

In the following potential measures are analysed for their potential for GHG reduction in the HDV sector.

5.2.2. ROLLING RESISTANCE FRIGHT

Due to optimisations in tyre design the rolling resistance values could be reduced by approx. 15%. Additional reductions could be reached by improving the road quality. But this is not likely to be realised in large scale until 2010. With the 15% reduction in the rolling resistance value the model PHEM calculates reductions in the fuel consumption by approx. -4% (urban driving) to -7% (highway driving). In total we thus may expect -6% in the specific fuel consumption by tyre optimisation.

The additional costs will be in the range of € 50.- per tyre. The additional costs are clearly overcompensated by the savings in fuel consumption for the average HDV if the costs including fuel taxes are considered. Without fuel taxes the result is still a slightly negative MAC of -3 €/ton of GHG reduction (Table 41).

The tyres have to be changed approx. every 100.000 km in any case, thus the measure could in theory be fully effective in 2008 on most HDV in Europe. This leads to a theoretical potential of 24 Mtonnes CO_{2eq} emissions in 2010.

In reality a high penetration of optimised tyres seems to be rather unrealistic. A necessary instrument to gain the benefits would be an obligatory labelling of tyres with the rolling resistance values (a corresponding test procedure would have to be defined). With such information the carriers can take fuel consumption into consideration when selecting the tyres. In the calculation of the reduction potential we assumed 50% of the HDV to drive with optimised tyres in the period from 2008 to 2012 (100% in 2020). However, this value is an expert judgement. A more sound evaluation should be based on questionnaires at carriers also. Such a study should be done in a next step, also to design the label.

	MAC	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a(2)]	[Mtonnes GHG /a (2)]
Reduced rolling resistance	-3	-6%	12.0 *(24.0)*	30.6 *(30.6)*

(1) reduction possible on new vehicles

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

Table 41 Technological potential of reducing rolling resistance values of HDV.

5.2.3. ENGINE IMPROVEMENTS

As described in the baseline scenario, EURO V and especially EURO VI will involve already a large bundle of high technology at the HD engines. It seems to be very unlikely to implement any additional outstanding technology to a large scale until 2010 since a lead time of approx. 3 years for development and testing of new technologies has to be assumed. Other options (alternative combustion concepts like HCCI, improvements of SCR efficiencies for NO_x removal etc.) exist in the long term but cannot be quantified yet.

In the longer term some additional measures together with evolutional improvements have potentials in the ranges given in Table 42.

	[%] change of fuel consumption (1)	**[%] change of purchase price (2)**	**remarks**
Evolutional improvements, improved automatic gearboxes,	-4%	+2%	
Water injection (or fuel water emulsion)	-4%	+3%	Technological barriers still exist

Table 42 Potential engine improvements.

In the simulation of the ideal reduction potential we assume in total -5% in fuel consumption of new HDV from 2010 on compared to the baseline with +3% vehicle costs. Due to the low rate of fleet penetration in the period from 2008 to 2012 the theoretical reduction potential of measures at the engines is only approx. -1% CO_{2eq} (i.e. 3.3 Mtonnes CO_{2eq}). For the year 2020 approx. 4.5% reduction in the GHG emissions from HDV traffic in EU25 are calculated as potential.

However, the MAC value is negative, thus we may expect evolutional improvements in the engine fuel efficiency – which are not known in detail yet - in any case in future compared to the assumptions in the baseline scenario.

To gain CO_2 reductions compared to the baseline scenario from this measure already in the period from 2008 to 2012 either fuel prices would have to further increase or other incentives would be necessary to stimulate an even more increased fuel efficiency of the HDV. However, measures to promote more fuel efficient HDV are difficult to elaborate. At the moment cost effective measures will be introduced by the manufacturers. An instrument to detect small differences in the fuel efficiency of HDV is not available yet. A standardised test on roller test beds with defined and highly accurate methods for the assessment of the real world driving resistances would be necessary to determine the potential differences between different makes and models of comparable HDV categories.

Since the introduction of such instruments will need time, the theoretical potential for the period from 2008 to 2012 most likely cannot be gained completely. We assumed a 20% utilisation. In the long term the testing of the complete vehicle could be more common already for in-use compliance tests and for type approval (NTE, Not To Exceed limits for real world driving). Accurate information on real world fuel efficiency may be gained on basis of such instruments. This information could assist in promoting the most fuel efficient technologies. For 2020 we thus optimistically assumed 100% utilisation of the theoretical potential.

	MAC	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Engine improvements	-33	-5%	0.67 (3.3)	22.6 (22.6)

(1) reduction possible on new vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

Table 43 Technological potential of Engine improvements at HDV.

5.2.4. REDUCTION OF AIR RESISTANCE

Within this measure the truck and the trailer could be improved to lower the air resistance force. This would need optimisations in design (included in the baseline scenario as long as no additional costs occur) and additional deflector plates. The possibilities of improvements concerning the truck are quite low, since the overall length of the HDV is restricted, and some improvements on the truck (drag coefficient) will lower the length and the maximum allowed weight of the trailer. The additional deflector plates add vehicle weight and thus reduce maximum allowed payload. Thus the improvements in terms of CO_2/ton-km are lower than per vehicle-km. Overall we can expect a technology potential of approx. 6% saving in fuel consumption by a reduced aerodynamic drag for the average HDV driving. Additional vehicle costs are in the range of +7.5% of the vehicle purchase price.

Since this measure concerns new registered vehicles, the potential is rather low in the short term, because the lifetime of a truck is approximately 5 to 8 years and the lifetime of the trailer is up to 20 years. Due to the low rate of fleet penetration in the period from 2008 to 2012 the overall reduction potential of improvements in the air resistance is only approx. -1% CO_{2eq}. In 2020 approx. 5.5% reduction in the GHG emissions from HDV traffic in EU25 are calculated.

For assessing the realistic potential, we assume that only HDV which are frequently used on highway operation will introduce this measure at new vehicles from 2008 on (which perform 80% of the HDV kilometres). Buses, garbage trucks and urban delivery vehicles do not implement this measure in the calculation since the cost effectiveness is low in these operation conditions (low influence of air resistance at low vehicle speeds).

Since the additional costs for the vehicle most likely are not compensated by the reduced fuel consumption additional measures would be necessary to exploit this potential. The related difficulties are already discussed in chapter 5.2.3.

	MAC	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Air resistance reduction	56	-6%	3.2 *(4.0)*	21.7 *(27.1)*

(1) reduction possible on new vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

Table 44 Technological potential of air resistance reduction at HDV.

5.2.5. DRIVER TRAINING

Keeping the engine speed in the region with highest fuel efficiency and a predictive driving style to avoid unnecessary accelerations can save substantial amounts of fuel compared to aggressive driving. However, we can assume that most drivers are trained to keep the HDV in the optimum range of engine speeds. The predictive driving style may not be wide spread within the drivers if time constraints exist in a delivery. At the traffic situation, which may have the highest shares in CO_2 emissions in EU25 HDV driving, namely the highway driving at approximately 87 km/h and flat road the influence of the driver on the fuel consumption is very low (as long as driving in the slipstream of the HDV in front is not allowed).

The numbers given in (Bates, 2001) in this content are quite reasonable and similar numbers are given in several studies, e.g. (Pischinger, 1998). From the literature and the simulation runs a theoretical potential of approx. 5% fuel saving was found for drivers which have regularly repeated trainings. Similar reductions were also found from companies and are reported in a EU project on Eco Drive (http://www.ecodrive.at/index.phtml). This number takes into consideration, that the driver will on average not realise "eco-driving" in 100% of his trips. In urban and rural driving the potential will be higher in highway driving much lower. The costs for the training of drivers is given in (Bates, 2001) with approx. 350 € (2005 value) per year and driver. The costs are considerably higher than those of the training of drivers of passenger cars due to the higher costs for the vehicles used during driving and due to the fact that the HDV drivers are trained during their working time causing costs to the hauling companies.

Similar to the effect of measures on new vehicles the training of drivers will need time to penetrate the HDV drivers. Instruments for increasing the share of driver trainings are increasing fuel costs or similar measures and the promotion of trainings for carriers. Nevertheless, it is very unlikely that 100% of the drivers in EU25 can be trained until 2012 (limited resources of educated trainers and infrastructure). Furthermore a reasonable share of drivers will not attend such trainings if they are voluntary since they may expect no high benefit.

For the assessment of the reduction potential we assumed that 20% of the drivers will change their driving style after trainings (=level of realisation). This gives an overall reduction potential of 1% of the EU25 CO_2 emissions from HDV (Table 45).

	MAC	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
Name of measure	[€/t]	[% red. ⁽¹⁾]	[Mtonnes GHG /a ⁽²⁾]	[Mtonnes GHG /a ⁽²⁾]
Driver training at HDV	-5	-5%	3.9 *(19.6)*	5.0 *(25.1)*

(1) reduction possible on new vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

Table 45 Technological potential of driver training at HDV.

5.2.6. LEAK REDUCTION REFRIGERATION

We found no additional data to (Blok, 2001). Thus we use the data given there as theoretical potential and for the MAC data. Due to the short time range available until 2008, we may assume that improvements on the air conditioning systems to reduce leakages on new vehicles can start earliest from 2008 on. Thus the level of implementation assumed here (30% for 2008 to

2012) takes into consideration that the time range available for implementing the measure is approx. 1/3 of the period assumed in (Blok, 2001).

	MAC	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Leak reduction Refrigeration HDV	29	-1%	0.9 *(3.0)*	3 *(3.0)*

(1) reduction possible on new vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

Table 46 Technological potential of Leak reduction Refrigeration at HDV.

5.2.7. FREIGHT LOGISTIC OPTIMISATION

In (Bates, 2001) a potential of maximum 15% to 20% reduction of GHG is stated without giving costs of the measures. In (Pischinger, 1998) a potential of 12% CO_2 reduction for improved logistic is given. The measure includes:

› Improved logistic organisation,

› Better co-ordination between all transport operators (also inter modal),

› Improved route planning.

For this set of measures (Bates, 2001) gives -11% in road freight vehicle kilometres, what is well in line with (Pischinger, 1998). Due to the increased loading of the vehicles the CO_2 reduction is a bit lower than the reduction of veh.-km (Table 47).

In (Pischinger 1998) the costs per ton CO_2 reduction are calculated to be approx. € -600. . These costs include all external costs of road transport (costs from accidents, noise, pollutants, time used for driving, etc.). In the actual study the costs for computer software and GPS infrastructure are taken into consideration while savings of fuel, driver salaries and a reduced vehicle fleet size give savings. Calculating the MAC with the data set used in the actual study leads to a MAC of approx. -220 €/ton. The value shows less savings than given in (Pischinger 1998), since the savings of external costs are not taken into consideration here.

To assess the theoretical total potential in EU25 we assumed the measure to be 100% realised from 2009 on. The resulting GHG reduction potential is quite high and seems to be very unrealistic to be exploited in reality by 2009. While logistic is improved within most carriers (e.g. GPS based planning) due to cost effectiveness and other advantages, the logistic between different carriers and between different modes of transport seems still to have a high potential which needs actions to be exploited. An important barrier seems to be the natural competition between the transport companies, which hamper the introduction of joint logistic systems. For the time period 2008 to 2012 a 20% level of implementation of a commonly optimised transport planning system in EU25 was assumed (50% for 2020).

	MAC	technology potential	reduction potential 2008-2012	reduction potential 2020
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Freight logistic optimisation	-220	-10%	6.2 *(31.4)*	25.1 *(50.1)*

(1) reduction possible on new vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

Table 47 Technological potential of freight logistic optimisation.

5.2.8. INCREASED WEIGHT LIMIT (44T)

Today in most EU25 countries the maximum allowed weight of truck+load is 40 tons. If the weight limit is increased to 44t, then 4t additional loading would be possible without changes of the vehicles. The effect is limited to the truck trailers and semi trailers designed for 40t in long distance transport. Smaller vehicles and also all trips which are not fully loaded are not affected by this measure.

With the model Phem the GHG emissions per ton-km for a 40 t EURO 4 semi trailer were simulated in average driving cycles. Then the same vehicle was loaded in the model with additional 4 tons (28.9 tons instead of 24.9 tons). The result are -9% in fuel consumption per ton-km.

To assess the total potential in EU25 data on the number of veh.-km which would be affected by the increased weight limit are missing completely yet. The available statistics on load factors in long distance transport suggest that approx. 25% of the HDV-km could be affected, thus the CO_2 reduction potential would be approx. -2%.

If 8.8 tons instead of 8 tons per axle are permitted (i.e. 44 t instead of 40t vehicle weight) then no change in the vehicle design would be necessary and nearly no costs at the vehicles would occur (wear of tyres and brakes will be higher). However, higher abrasion of the road surface has to be expected with higher loads per axle. The costs of higher abrasion of the road surface are not included in the MAC in Table 48.

As level of implementation 100% were assumed since this measure is fully effective with the political decision (only a short period of time is necessary for the carriers to adapt the planning).

	MAC	technology potential	reduction potential 2008-2012	reduction potential 2020
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Increased weight limit (44t)	-97 (3)	-9%	7.9 *(7.9)*	10.0 *(10.0)*

(1) reduction possible on new and full loaded vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

(3) The costs of higher abrasion of the road surface are not included

Table 48 Technological potential of increased weight limit (44t).

5.2.9. INCREASED WEIGHT LIMIT (60T)

In Scandinavian countries truck trailers mass limit is 60t. If full loaded vehicles are compared, then the 60t vehicle is more fuel efficient per ton-km. A simulation with Phem gave a 20% reduction in the fuel consumption per t-km for the 60 ton truck trailer compared to a standard 40t truck trailer. As already for the 44t limit, the main uncertainty in the assessment of the reduction potential is the number of veh.-km which would benefit from 60 ton limits and how many veh.-km would have higher fuel consumption per ton-km. E.g. low loaded driving needs more fuel per t-km for the 60 ton truck. Additionally 60 ton truck trailers can be used in long distance driving only due to the increased length of the vehicles. However, if 60 ton trucks would penetrate the market, the logistic would adapt to the increased loading capacity of the trucks. In total we can make a rough estimation, that 20% of the HDV-km would gain the full benefit of the increased load limit. Thus the total potential of the measure is approx. -4% CO_2.

The costs of a 60 ton vehicle would be approx. 35% higher than for a 40 ton truck but the possible payload is more than 50% higher than for the 40 ton vehicle. Additionally less driver costs and fuel costs per ton-km occur. This results in lower costs per ton-km for the 60 ton vehicle. With constant 8t per axle limit, the abrasion of the road surface should not increase.

Since the implementation of this measure needs new vehicles in most of the EU25, in 2008 to 2010 the technology potential can not be fully exploited. As level of implementation 100% were assumed for 2008 to 2012 and for 2020 (i.e. 60t limit in all EU25 countries from 2008 on).

	MAC	technology potential	reduction potential 2008-2012	reduction potential 2020
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Increased weight limit (60t)	-58	4%	11.8 *(11.8)*	20.1 *(20.1)*

(1) reduction possible on new and full loaded vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

(3) eventual costs of higher abrasion of the road surface are not included

Table 49 Technological potential of increased weight limit (60t).

5.2.10. LIGHTWEIGHT CONSTRUCTION

Lightweight construction of HDV saves fuel due to the lower vehicle mass (if not full loaded) and the resulting reduced driving resistances. If full loaded, the lightweight vehicle can load more tons than the standard vehicle, thus the fuel consumption per ton-km is lower for the lightweight vehicle. A simulation run with the model Phem gave for 18% reduction of the vehicle weight -5% for a not full loaded vehicle and -11% in fuel consumption per ton-km for full loaded vehicles. Lower reductions in the vehicle weight give nearly linearly reduced effects. In total we could expect a potential of approx. -7% CO_2 emissions per "-18%" lightweight vehicle.

The additional vehicle costs for -18% in vehicle mass are approx. +50%, for -8% mass approx. +20%. Lightweight vehicles would cause rather lower abrasion of the road surface, but these effects are not included in the MAC value. However, the costs per ton of CO_2 reduction are rather high with this measure due to the high vehicle costs.

If the measure is started 2007, we would not have a full penetration of the fleet in 2008 to 2012. Thus the total reduction potential in EU 25 is lower than the technological potential of -7%. The effect in the EU25 fleet was calculated with the model GLOBEMI again. As level of implementation, it was assumed in the simulation, that 100% of the new registered HDV from 2009 on will be made with extensive light weight construction gaining 7% lower fuel consumption per t-km.

	MAC	technology potential	reduction potential 2008-2012	reduction potential 2020
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Lightweight construction	+858 (3)	7%	7.6 *(7.6)*	32.4 *(32.4)*

(1) reduction possible on new and full loaded vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

(3) eventual savings due to lower abrasion of the road surface are not included

Table 50 Technological potential of lightweight construction.

5.2.11. SPECIFIC LONG DISTANCE VEHICLES

The HDV are usually designed to sustain stress of worst case usage (e.g. 100% in construction sides). The stress in long distance driving on highway is lower for many components than in the worst case usage (e.g. suspension). If special long distance vehicles are constructed, where the dimension of the components is adapted to lower stress, the vehicle weights of this HDV would be reduced. The costs of such specific vehicles would be much lower than the "lightweight" vehicles described in chapter 5.2.10. Approx. +10% vehicle costs are assumed to obtain approx. 10% reduction in the vehicle weight of such special HDV. The resulting fuel saving would be -4%.

Since only new vehicles could be designed in this way, the fleet penetration has to be taken into account for the assessment of the total potential in EU25. The total emissions in EU25 were calculated with the model GLOBEMI again. It was assumed in the simulation, that 100% of the new registered long distance HDV (i.e. semi trailers and truck trailers >35t) from 2009 on will be made less robust with reduced weight gaining 4% lower fuel consumption per t-km.

	MAC	technology potential	reduction potential 2008-2012	reduction potential 2020
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Specific long distance vehicles	+226 (3)	-4%	3.3 *(3.3)*	14.3 *(14.3)*

(1) reduction possible on new and full loaded vehicle

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

(3) eventual savings due to lower abrasion of the road surface are not included

Table 51 Technological potential of specific long distance vehicles.

5.2.12. BIO DIESEL

Biodiesel (FAME, according to EN 14214) is made via esterification from different feedstock (Rapeseed, Sunflower, soja oil, palm oil, animal fat, …) on a global level. EU target for 2010 is to increase the share of renewable fuels in the transport sector (2003/30/EG). In the baseline scenario a level of 5.75% bio diesel on the total fuel consumption of the EU25 HDV traffic was assumed.

As additional measure here a 10% blend of biodiesel in fossil diesel was assumed (instead of the 5.75%) since this share of biodiesel most likely is compatible for almost all HDV. Certainly the amounts of biodiesel necessary for this measure is high and will have to be imported to a large extent (additional 4.25% of the fuel consumption of HDV as biodiesel). Also additional production facilities would be necessary on global level to satisfy the additional demand. The implementation of this measure may be forced by lowering tax burdens for 10% biodiesel-blends to an extent that the blends are cheaper than pure fossil diesel.

For fuels from renewable sources the main question is the reduction of GHG emissions to be assumed for the calculation. A fair comparison needs a life cycle analysis since biofuels usually have clearly higher emissions during the production process (especially N_2O during the farming) than fossil fuels but usually zero CO_2 emissions are attributed to the vehicle exhaust gas emissions when biofuels are used. In the simulation a reduction of 45% in the life cycle GHG emissions was used as model input. The values are based on a mixture of feedstock for biodiesel production given in Figure 26.

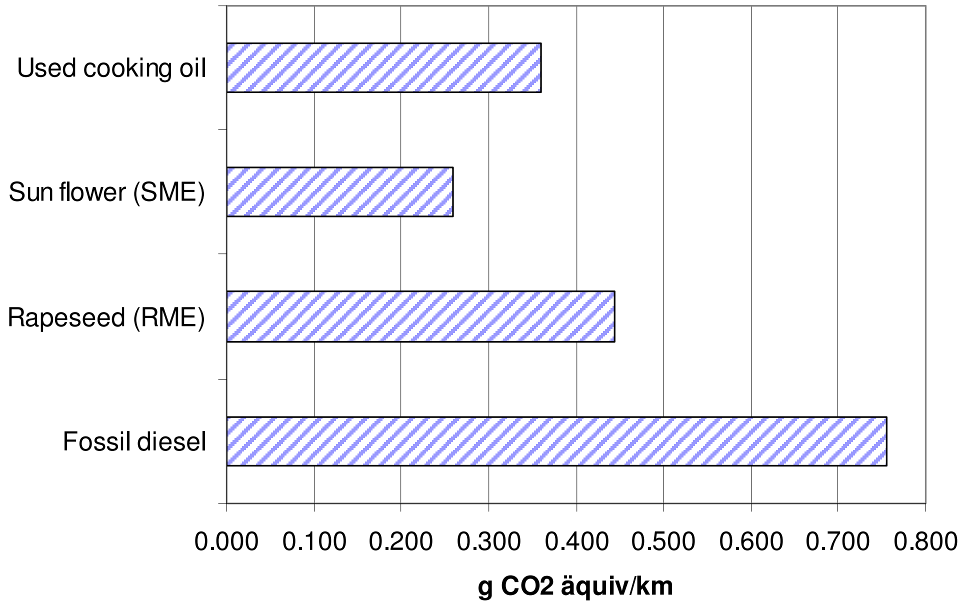


Figure 26 Life cycle GHG emissions from bio diesel and fossil diesel for the use in HDV according to Jungmeier (2004) and Blassnegger (2005).

Some open questions would have to be clarified before implementing higher blends of bio diesel. Bio diesel is known to reduce PM, HC and CO emissions but causes higher NO_x raw emission levels. Approximately +20% NO_x can be expected when 100% bio diesel is used, a 10% blend thus will cause about +2% NOx (e.g. Hausberger et.al. 2006a, Hausberger et.al. 2006b). Since the AdBlue dosing of HDV equipped with SCR is adjusted to the NO_x-levels from the use of fossil diesel, the AdBlue dosing from current SCR technology is not adequate for the use of bio diesel. Without the adequate level of the reducing agent (NH_3 from the AdBlue), the additional NO_x emissions are not reduced by the SCR. Thus all extra NO_x raw emissions due to the usage of bio diesel will be found also after the SCR. Assuming a 85% efficiency of the SCR for EURO VI, 2% extra NO_x raw emissions from a 10% blend will cause more than 10% higher tail pipe emissions. Future solutions could be e.g. a sensor to detect the fuel properties or a (closed) loop control of the SCR with a NO_x sensor or simply the adaptation of the reference fuel for the type approval test.

An other open question is the proper function of the regeneration of particle filters when bio diesel is used. The timing of the late fuel injection to heat the filter in driving conditions where the exhaust gas temperature is too low for regeneration usually is adapted to the properties of fossil diesel. Due to slightly different fuel properties of the bio diesel the fuel might not inflame properly during phases of late injection. This could lead to a dilution of the lube oil and damages on the engine and to damages of the filter . However, these concerns are more relevant for higher blends. For 5% blends of biodiesel in fossil diesel all vehicles are released, for 10% blends no additional troubles are known yet.

The costs of biodiesel are higher than for fossil diesel. When no mineral oil taxes are added to the costs of biodiesel then the price is competitive to fossil diesel with taxes. Here the costs excl. taxes are taken into consideration, thus biodiesel adds high additional fuel costs (Euro 0.53 instead of 0.3 per litre) and small additional costs due to the division in half of the oil changing intervals.

	MAC	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
Bio Diesel	243 (3)	-20% to -90%(4)	7.5 *(7.5)*	9.6 *(9.6)*

(1) reduction possible on new and full loaded vehicle (5.75% biodiesel blend)

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented (i.e. 10% biodiesel blend)

(3) costs without taxes. For the carrier the costs are rather similar to the fossil diesel

(4) the CO_2 reduction potential of bio fuels over the life cycle depends very much on the feedstock and the production process. Using e.g. rapeseed with extensive agriculture leads to rather small CO_2 savings in the live cycle compared to fossil diesel while e.g. the usage of old cooking oil shows high CO_2 reduction values since nearly no greenhouse gases are emitted in the production process. For the EU GHG balance the effects of the usage of bio fuel may show even larger scattering. Imported biomass will cause only small GHG emissions in the EU inventory (transportation of the feedstock only) while biomass produced in the EU can cause substantial GHG emissions from the agricultural sector.

Table 52 Technological potential of Bio Diesel in HDV.

5.2.13. ALTERNATIVE PROPULSION SYSTEMS

Different alternatives to the diesel engine exist today:

- **Compressed natural Gas (CNG):** the efficiency of the CNG engine is lower than the efficiency of the HD diesel engines. Depending on the engine concept (lean burn or stoichiometric for CNG) and the cycle, the energy consumption of CNG driven HDV is 5% to 25% higher than today's diesel driven HDV. In congested bus routes the additional energy demand of CNG engines is reported to be up to 60% higher than with diesel engines (Bates, 2001). Due to the lower Carbon content per MJ fuel, the CO_2 exhaust gas emissions from CNG driven HDV usually are still below the emissions of diesel (approx. -20% on average). Due to the higher CH_4 emissions from CNG engines and potential leakages in the fuel production and distribution, the overall GHG emissions of CNG and diesel are very similar for HDV. Thus no reduction potential is given here.
- **Hybrid Concepts**, e.g. a diesel engine combined with an electric motor, do have advantages in the energy efficiency if a sufficient amount of braking energy can be recuperated and if engine start stop functions can be applied over a longer period of stand still. To which amount energy can be saved and what additional vehicle costs occur can vary widely for different hybrid concepts. In the HDV sector especially the city buses offer a potential for hybrids. We can expect reductions in fuel consumption of HDV by 0% (highway) to 20% (congested urban

bus route). The costs of hybrid buses are approx. 10% to 20% higher than comparable diesel buses.

› **BTL, GTL, H2**: these fuels are not assumed to have larger potentials in the period 2008 to 2012 and are not analysed here.

In the simulation an implementation level of 20% of the city buses was defined to be diesel hybrid concepts with 15% reduction in fuel consumption compared to diesel buses for the period 2008 to 2012. For 2020 a share of 50% hybrid concepts in city buses was assumed. Due to the rather small number of vehicles, the overall potential is also small. However, depending on the hybrid design, the savings in fuel consumption could compensate the additional vehicle costs in urban driving for HDV carrier. If fuel costs without taxes are taken into consideration, the MAC value is 153 €/ton.

	MAC	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
Name of measure	[€/t]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
diesel hybrids in city buses	153	15% (3)	0.5 *(2.6)*	1.4 *(2.8)*

(1) reduction possible on new and full loaded vehicle (5.75% biodiesel blend)

(2) reduction possible in the total fleet of EU25 for the given period. In brackets: maximum theoretical potential if measure is fully implemented

(3) for city buses

Table 53 Technological potential of diesel hybrids in city buses.

5.2.14. TOTAL HDV

The assessment of the marginal abatement costs (MAC) in the HDV sector in EU25 is related to several uncertainties, both in definition of reduction potentials and in the allocation of costs. Data on modern technologies where costs and reduction potential are quantified can hardly be found in literature, thus a questionnaire and interviews are the main source of the data used here. Typically these methods can give good estimations of the magnitudes of the values, but due to time constraints from the people interviewed and/or filling in the questionnaires no precise values can be expected. Nevertheless the data obtained shall give a useful order of magnitude of the costs and potentials and are summarised in Table 54. If measures shall be realised in future a detailed planning would be necessary in any case where additional data for more accurate evaluations shall be available.

	Marginal abatement costs	**technology potential**	**reduction potential 2008-2012**	**reduction potential 2020**
No. Name of measure	[€/t CO_{2eq}]	[% red. (1)]	[Mtonnes GHG /a (2)]	[Mtonnes GHG /a (2)]
1) Freight logistic optimisation	-219	-10%	6.3	25.1
2) Increased weight limit (44t)	-97	-9%	7.9	10.0
3) Increased weight limit (60t)	-58	-4%	11.8	20.1
4) Engine improvements	-33	-5%	0.7	22.6
5) Driver training at HDV	-5	-5%	3.9	5.0
6) Reduced rolling resistance	-3	-6%	16.8	30.6
7) Leak reduction Refrigeration	29	-1%	0.9	3.0
8) Air resistance Freight	56	-6%	3.2	21.7
9) Diesel hybrids in city buses	153	15% (3)	0.5	1.4
10) Spec. long distance vehicles	226	-4%	3.3	14.3
11) Bio Diesel	243	-30 to -100	7.5	9.6
12) Lightweight construction	859	-7%	7.6	32.4

(1) reduction possible on new vehicle

(2) reduction possible in the total fleet of EU25 for the given period

(3) for city buses

Table 54 Marginal abatement costs (MAC) and GHG reduction potential identified for measures in the HDV sector in EU 25.

If the single potentials are simply added, we have a total reduction potential in the period 2008-2012 of 65 Mtonnes CO_{2eq} GHG emissions. However, this is not the real reduction potential since the effects of measures must not be added since otherwise the same ton of GHG would be reduced several times (e.g. t-km already reduced by better logistic can not be improved in fuel efficiency). The sum of measures may in reality have less than 50 Mtonnes CO_{2eq} GHG emissions.

Comparing the results from the actual study with (Blok, 2001) gives similar magnitudes in the marginal abatement if plotted over the relative contribution of each measure to the overall GHG reduction potential. However, the absolute values for the reduction potential are higher in the actual study if also expensive measures are considered (Figure 27). This is mainly due to the fact, that the actual study included much more measures in the HDV sector than (Blok, 2001).

MARGINAL ABATEMENT COSTS FOR THE HDV SECTOR: PAM1+

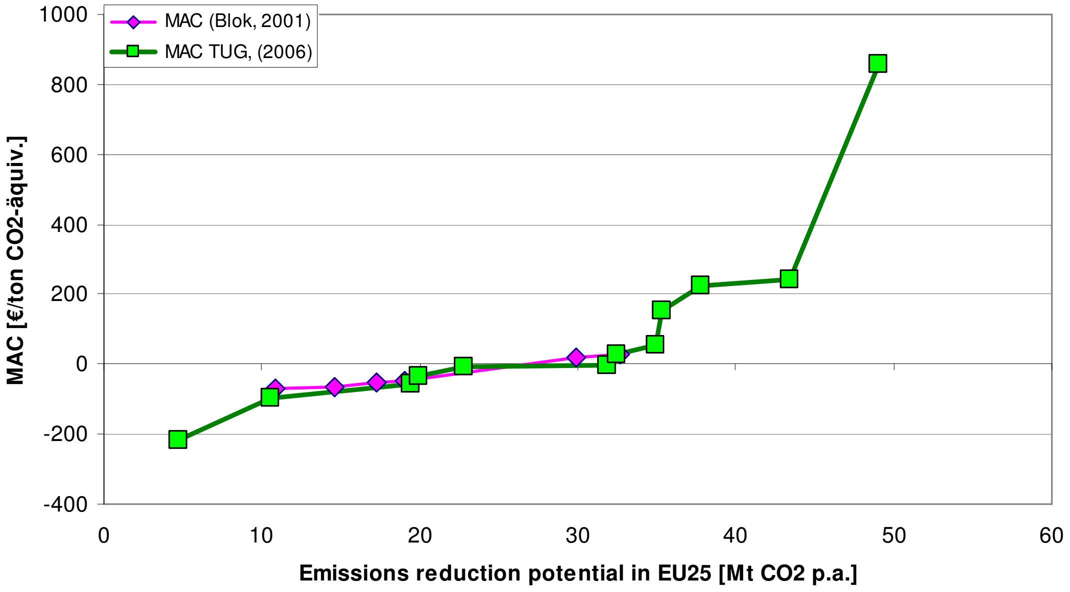


Figure 27 MAC and the relative cumulated contribution of the measures (PAM1+) to the total GHG reduction in the HDV sector.

5.3. SUMMARY AND CONCLUSIONS

The cost-effectiveness of the measures in the transport sector has been assessed using new material from recent studies (passenger car and light commercial vehicles, Task A as reported in (TNO 2006)) or had to be re-assessed separately for this study (for heavy duty vehicles) since comparable information was scarce. In this respect the transport sector was treated differently and unlike the non-road sectors.

Figure 28 shows the marginal abatement costs of the three subsectors of transport (passenger, freight, van). The figure indicates a higher potential for freight (40 – 50 Mtonnes/a) compared to passenger traffic (30 – 35 Mtonnes/a) while the potential for van is limited. At the same time the costs in the freight sector are assessed as considerably lower than in the passenger segment: measures with a reduction potential up to 30 Mtonnes/a seem feasible at zero or even negative costs while the costs for reducing the CO2-emissions of passenger cars are assessed at about 100 €/t CO2-eq up to (only) 10 Mtonnes/a and at 170 €/t CO2-eq up to 30 Mtonnes/a.

MARGINAL ABATEMENT COSTS OF TRANSPORT: PAM1+

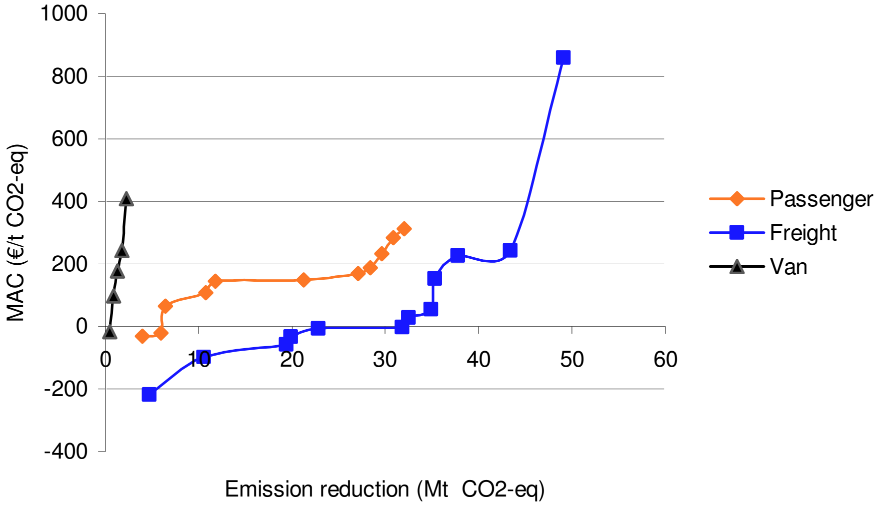


Figure 28 MAC curve for policies and measures additional to the planned measures of scenario S1 (PAM1+) of the transport sector for EU25.

For passenger cars, the technical options to reduce fuel consumption at the vehicle level tend to be in the upper range of the cost level (146 €/t CO2-eq for reducing average CO_2 emissions from 140 to 135 g/km at up to 283 €/t CO2-eq for reducing average CO_2 emissions from 125 to 120 g/km). Also the alternative fuel options show higher costs (biofuels: 170 €/t CO2-eq, CNG: 312 €/t CO2-eq). The most cost-effective measures (with negative costs) are behavioural measures (fuel efficient driving, tyre pressure monitoring).

Similarly for HDV: the more technical measures show higher costs while behavioural measures (e.g. freight logistics) are assessed as very cost-effective measures (~-200 €/t CO2-eq) with considerable potential. Two particular measures (increasing the weight limit to 44t or even 60t are also considered as cost-effective (i.e. negative costs), however the associated market potential has a significant uncertainty margin.

A comparison with the “lead study” (Blok et al 2001) reveals that the new potentials for passenger cars in this study are expected to be considerably lower than in Blok et al (i.e. 32 Mtonnes/a compared to 83 Mtonnes/a), while for freight the “new” potentials (49 Mtonnes/a) are higher than in Blok et al (33 Mtonnes/a). However, the latter is due to the fact that the new potentials include several additional measures which have not been taken into account in the previous study; the costs for the same measures remain comparable. This is different in the passenger car segment (Figure 29): here the new MACs are considerably higher compared to Blok et. al. while the potential is reduced significantly - despite the fact that we applied in this study a “optimistically realistic” approach for assessing the potentials. This approach accounts for the full technical potential but takes into account the basic dynamics over time determined by aspects such as the fleet renewal rate or lifetime of the product. The reduced reduction potential in this study is mainly due to the fact that the timeframe available (2008-2012) for the market penetration of measures which are associated with new vehicles is comparatively short. These measures though will continue to be effective beyond the year 2012, therefore the overall reduction will evolve over time and the reduction potential of these measures will increase considerably in the future.

COMPARISON OF THE UPDATED MAC CURVE

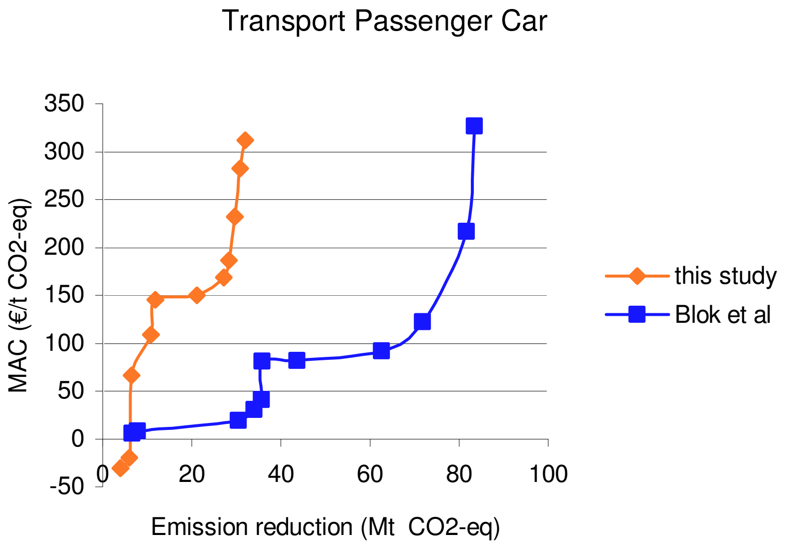


Figure 29 The new MAC for passenger cars are considerably higher compared with Blok et al (2001)

6. QUANTIFICATION OF EMISSION SCENARIOS 2010

6.1. BASELINE SCENARIO (SCENARIO 0): MEASURES IN PLACE

In the report two emission scenarios have been quantified. The emission scenarios are needed to know the starting point for the emission reducing measures discussed in the earlier chapters. The measures reduce the emissions from a certain level, called baseline. Both emission scenarios described in this chapter can be used as baselines from which emissions are reduced. In most cases in this report, scenario 1 is used as the baseline. However, we begin by describing a scenario 0 (sometimes referred to as baseline scenario), as scenario 1 relies on the definition of scenario 0.

Scenario 0 is presented in Table 55 (EU25), Table 56 (EU15) and Table 58 (EU10). For EU25 the transport sector has been divided into sub-categories in Table 56.

The scenario 0 is mainly based on PRIMES (2005). For non-CO_2 GHG (greenhouse gas) the PRIMES-data[34] have been complemented by emission data from the baseline used in Blok (2001b).

PRIMES (2005) is a baseline scenario that includes current policies (in 2005) on energy efficiency and renewables, without assuming that specific targets are necessarily met. For transport the baseline assumes that the target of 140 gram / km for new cars in 2008 as stated in the voluntary agreement between the car industry and the European Commission is achieved. However the PRIMES data does not assume any further strengthening of the targets thereafter and the 120 g / km is then not included in the scenario 0 of this study[35]. The biofuel directive is included and for EU25 an average use of 3.9% biofuels in the transport sector for 2010 is assumed. The European Emission Trading Scheme (EU-ETS) is also included with a relatively low carbon price (5 € / ton CO2) for the sectors included in the EU-ETS. For further information about the assumptions made in the PRIMES data used for scenario 0 of this study we refer to Mantzos and Capros (2006).

---

[34] PRIMES data only include CO_2 and no other GHG.

[35] As discussed below the 120 g / km target is not included in scenario 1 either, as scenario 0 and scenario 1 are considered equal regarding the transport sector.

		EEA (2005a)		Scenario 0 for 2010	
Mtonnes CO_{2eq}	**Base year (Emissions in 1990 or 1995)[36]**	**Emissions in 2003[37]**	**Change from base year[38]**	**Emissions in 2010**	**Change from base year**
Energy supply (CO_2 emissions)[39]	1662	1537	-7.5%	1 642	-1.2%
Energy supply (non-CO_2 GHG emissions)	76	54	-28.9%	57	-25.0%
Fossil fuel extraction, transport and distribution	124	72	-41.9%	77	-37.9%
Industry	1775	1542	-13.1%	1653	-6.9%
Transport	782	957	22.3%	1016	29.8%
Households	964	876	-9.1%	872	-9.5%
Services	568	518	-8.8%	582	2.5%
Agriculture	595	505	-15.1%	507	-14.8%
Waste	218	152	-30.3%	100	-54.1%
Total[40]	5102	4676	-8.4%	4864	-4.7%

Table 55 Emissions in base year, 2003 and in the scenario 0 (2010) for EU25. The total emissions in 2003 are about 8% lower than in the base year (EEA 2005a and 2005b).

Transport sector (EU25)		**Scenario 0**	
Mtonnes CO_{2eq}	**Emissions base year (1990)**	**Emissions in 2010**	**Difference from base year**
Road transport	691	916	32.7%
Public road transp.	24	21	-13.3%
Motorcycles	6	7	25.9%
Private cars	412	491	19.2%
Trucks	249	397[41]	59.4%
Rail	48	51	5.0%
National aviation	22	30	37.2%
Inland navigation	21	18	-13.3%
Total	782	1016	29.8%

Table 56 Emissions in the transport sub-sectors in the base year and in scenario 0 (2010) for EU25. The transport sector emissions will increase by more than 30%. Emissions from international aviation and navigation are much larger than the national counterparts and are growing more rapidly (EEA 2005b).

---

[36] The base year is used for evaluating the fulfilment of the Kyoto agreement. Base year emissions are not equal to emissions in 1990. However, for a majority of the emissions, 1990 is the base year, but there are some exceptions. For F-gases most countries in EU use 1995 as base year and many of the countries in EU10 use different years in the 1980-ies as base year for most of their emissions. (EEA 2005a)

[37] The recalculated values for 2003 are the base year emissions in the baseline scenario changed by the percentage difference between the base year and the emissions for 2003 in EEA (2005b) for each sector.

[38] The change between the emissions in the base year and in 2003 is according to EEA (2005b).

[39] The CO_2 emissions in the Energy supply sector are distributed as indirect emissions to the other sectors

[40] The total does not include the Energy supply (CO_2-related) sector, as these emissions are included in the other sectors as indirect emissions.

[41] The HDV, as described earlier in the report, does not correspond totally with this number. The reason for this is that some HDV vehicles (such as trucks and some busses) are included in the emissions for public road transport in the table above.

Mtonnes CO_{2eq}	Base year (Emissions in 1990 or 1995)[42]	EEA (2005a) Emissions in 2003[43]	EEA (2005a) Change from base year[44]	Scenario 0 for 2010 Emissions in 2010	Scenario 0 for 2010 Change from base year
Energy supply (CO_2 emissions)[45]	1 269	1 299	2.4%	1 300	2.4%
Energy supply (non-CO_2 GHG emissions)	58	44	-24.1%	45	-22.4%
Fossil fuel extraction, transport and distribution	95	53	-44.2%	61	-35.8%
Industry	1 374	1 262	-8.2%	1 341	-2.4%
Transport	717	882	23.0%	919	28.1%
Households	769	779	1.3%	736	-4.3%
Services	445	452	1.6%	482	8.3%
Agriculture	451	405	-10.2%	388	-14.0%
Waste	166	114	-31.3%	80	-51.8%
Total[46]	4 075	3 991	-2.1%	4 052	-0.6%

Table 57 Emissions in base year, 2003 and in the scenario 0 (2010) for EU15. The total emissions in 2003 are about 2% lower than in the base year (EEA 2005a and 2005b).

---

[42] The base year is used for evaluating the fulfilment of the Kyoto agreement. Base year emissions are not equal to emissions in 1990. However, for a majority of the emissions, 1990 is the base year, but there are some exceptions. For F-gases most countries in EU use 1995 as base year and many of the countries in EU10 use different years in the 1980-ies as base year for most of their emissions. (EEA 2005a)

[43] The recalculated values for 2003 are the base year emissions in the baseline scenario changed by the percentage difference between the base year and the emissions for 2003 in EEA (2005b) for each sector.

[44] The change between the emissions in the base year and in 2003 is according to EEA (2005b).

[45] The CO_2 emissions in the Energy supply sector are distributed as indirect emissions to the other sectors

[46] The total does not include the Energy supply (CO_2-related) sector, as these emissions are included in the other sectors as indirect emissions.

Mtonnes CO_{2eq}	Base year (Emissions in 1990 or 1995)[47]	EEA (2005a)		Scenario 0 for 2010	
		Emissions in 2003[48]	Change from base year[49]	Emissions in 2010	Change from base year
Energy supply (CO_2 emissions)[50]	393	263	-33.2%	342	-13.2%
Energy supply (non-CO_2 GHG emissions)	18	9	-50.0%	12	-33.3%
Fossil fuel extraction, transport and distribution	29	19	-34.5%	16	-44.8%
Industry	401	276	-31.2%	312	-22.2%
Transport	65	78	19.5%	97	48.4%
Households	195	116	-40.5%	136	-30.3%
Services	123	76	-38.2%	100	-18.7%
Agriculture	144	85	-41.0%	119	-17.4%
Waste	52	39	-25.0%	21	-59.6%
Total[51]	1 027	698	-32.1%	813	-20.9%

Table 58 Emissions in base year, 2003 and in scenario 0 (2010) for EU10. The total emissions in 2003 are 32% lower than in the base year (EEA 2005a and 2005b).

The PRIMES (2005) data and the baseline from Blok (2001b) used for constructing the scenario 0 have been adjusted in a number of ways, to achieve an accurate baseline scenario for the analysis in this project.

The PRIMES data have been adjusted by excluding international aviation, which is included in PRIMES. The Blok (2001b) baseline data has been updated with respect to decreased emissions of N_2O (Riemersma) in road transport and with more updated figures for the agriculture and waste sectors[52]. Furthermore, the Blok (2001b) baseline only represents EU15 and therefore the figures are adjusted to represent the EU25.

The non-CO_2 emissions for EU10 (the new EU member states included in EU25 but not in EU15) are based on the assumption that the proportion of these gases in relation to fuel related CO_2 emission is the same in EU10 as in EU15.

The scenario 0 in Table 55 is presented with the sector structure used in Blok (2001a and 2001b), i.e. the same sector structure used in Eurostat and PRIMES (Blok, 2001a). The emissions are allocated to the user sectors including both direct and indirect emissions. This means that indirect fuel related CO_2 emissions from electricity and heat, e.g. used in the household

---

[47] The base year is used for evaluating the fulfilment of the Kyoto agreement. Base year emissions are not equal to emissions in 1990. However, for a majority of the emissions, 1990 is the base year, but there are some exceptions. For F-gases most countries in EU use 1995 as base year and many of the countries in EU10 use different years in the 1980-ies as base year for most of their emissions. (EEA 2005a)

[48] The recalculated values for 2003 are the base year emissions in the baseline scenario changed by the percentage difference between the base year and the emissions for 2003 in EEA (2005b) for each sector.

[49] The change between the emissions in the base year and in 2003 is according to EEA (2005b).

[50] The CO_2 emissions in the Energy supply sector are distributed as indirect emissions to the other sectors

[51] The total does not include the Energy supply (CO_2-related) sector, as these emissions are included in the other sectors as indirect emissions.

[52] For the waste and agricultural sectors, the forecasted decrease in the scenario with existing policies and measures in EEA (2005a) has been used.

sector, are allocated to the household sector, and likewise for indirect emissions caused by other sectors. In the Table 55, Table 56 and Table 57 these emissions are also separately presented under Energy supply (CO_2 related)[53].

Comparison between the scenario 0 and the scenario with existing policies and measures presented in EEA (2005a)

The scenario 0 selected in this project corresponds approximately to the EEA scenario including existing domestic polices and measures (EEA 2005a). In Table 59 a comparison between these scenarios for EU15 is presented[54]. A perfect comparison between the scenarios is impossible because of different sector definitions and lack of data on sector level for some countries in EEA (2005a). In Table 58 the emissions in the baseline scenario of this project have therefore been redistributed to match the EEA scenario as good as possible.

	Scenario 0		**EEA scenario with existing measures**	
Mtonnes CO_2 eq	**Emissions in 2010**	**Difference compared to base year**	**Emissions in 2010**	**Difference compared to base year**
Energy sector (excluding transport)	2418	-2.8%	2426	-4.6%
Transport[55]	884	17.4%	927	31.1%
Industry (not fuel related CO_2 emissions)	335	0.8%	360	0.8%
Agriculture (not the fuel related CO_2 emissions)	334	-16.5%	385	-16.5%
Waste (not the fuel related CO_2 emissions)	80	-52.2%	67	-52.2%
Total as written in the report	4051	-2.1%	4080	-1.6%
Check (the sector emissions are added together)[56]	4051	-2.1%	4165	-1.0%

Table 59 Comparison of scenario 0 and the EEA-scenario "with existing policies and measures" (EEA 2005a). The emissions correspond to EU15.

The differences between the baseline scenario and the EEA scenario can be explained by the different approaches used for calculating the scenarios. The PRIMES model is a modelling system that simulates a market equilibrium solution for energy supply and demand in the EU mem-

---

[53] To avoid double counting the Energy supply (CO_2 related) is not included in the sum of the emissions.

[54] The comparison analysis is only presented for EU15 because the data availability has been best for this region. However, similar results are likely for the other regions too.

[55] The number differs from the corresponding number in figure 7.3. The reason for this difference is that figure 7.3 includes indirect emissions resulting from use of electricity in the railroad sector.

[56] The total number does not correspond to the sum of the sectors. The major reason is that Spain only includes fuel-related CO_2 emissions in the total emissions, whereas all emissions from Spain are included in the sectors.

ber states (Blok, 2001c). The PRIMES data includes activity, technology, energy use and fuel related CO_2 emissions for every fifth year between 1990 and 2030.

The EEA scenario on the other hand is developed by adding together the member states own projections, developed under the UNFCCC framework and that in most cases are described in the national communications (EEA 2005a). The methodology used for developing the scenarios and the assumptions differs between the member states, as they use different models, years for calculation, base years, fuel prices etc. Furthermore, some of the countries don't even provide sector specific emissions, and thus sector specific projections have to be assumed e.g. according to the projected changes for the other member states.

In addition, the policies and measures assumed to be included in the scenario "with existing domestic policies and measures" vary for each member states. This is probably to a large extent depending on which policies and measures that have actually been implemented in the respective country[57].

Even if there are lots of weaknesess in the EEA scenario, it is a scenario including all GHG and that uses the knowledge in all the different countries for predicting the future emissions. Whether this project's scenario 0 or the EEA scenario with existing domestic policies and measures is the best projection is very hard to tell. However, it is interesting to compare the scenarios, since they are based on different methodologies.

6.2. SCENARIO 1: PLANNED MEASURES

Scenario 1 is presented in Table 60 (EU15) and Table 59 (EU25). The intention has been to define a scenario that corresponds to the scenario with additional domestic policies and measures in EEA (2005a), has the same sector structure as in (Blok 2001a) and is consistent with the scenario 0 defined for this project.

To match the Blok sector structure, data from the EEA scenario has been transformed by distributing the emissions of the energy sector (defined as in EEA (2005a)) between the different sectors assuming the same distribution as the energy emissions in the scenario 0 for 2010. This is considered a reasonable approximation.

The percentage decrease between the two scenarios in EEA ("with existing policies and measures" and "with additional policies and measures") for EU15 for every sector is used to calculate the scenario 1 from the scenario 0 (see Table 60).

---

[57] For the transport sector most countries have implemented the voluntary agreement of the 140 g / km for new passenger cars but very few have implemented the 120 g / km target.

	Scenario 0, 2010		**Scenario 1, 2010**		**EEA-scenario with additional domestic policies and measures**	
Mtonnes CO2 eq	**Emissions**	**Change from base year in baseline scenario**	**Emissions**	**Change from base year in baseline scenario**	**Emissions 2010**	**Change from base year in EEA (2005a) scenario**
Energy supply (CO_2 emissions)[58]	1300	2.4%	1246	-1.8%	1118	-8.6%
Energy supply (non-CO_2 GHG emissions)	45	-22.4%	43	-25.0%	57	-8.6%
Fossil fuel extraction, transport and distribution	61	-35.8%	58	-38.9%	58	-8.6%
Industry	1341	-2.4%	1260	-8.3%	1281	-9.0%
Transport	919	28.1%	919	28.1%	908	22.2%
Households	736	-4.3%	706	-8.2%	704	-8.6%
Services	482	8.3%	462	3.8%	460	-8.6%
Agriculture	388	-14.0%	381	-15.5%	431	-16.8%
Waste	80	-51.8%	80	-51.8%	67	-52.6%
Total[59]	4052	-0.6%	3909	-4.1%	3965	-5.8%

Table 60 Emissions in scenario 0 and scenario 1 for EU15 in 2010. Scenario 1 is developed by multiplying the scenario 0 for 2010 by the percentage difference for every sector between the EEA scenarios with existing measures and with additional measures.

The scenario 1 for EU15 will decrease the emissions by 4% compared to the base year. This decrease is smaller than the one forecasted in the scenario “with additional measures” in EEA (2005a) (-5.8%).

The scenario 1 for EU25 cannot be calculated with the same methodology as for EU15 due to lack of sector data for EU10. To calculate the scenario 1 for EU25 it is therefore assumed that there is no change between baseline scenario for 2010 and scenario 1 for EU10[60]. The scenario 1 for EU25 is presented in Table 59.

---

[58] The CO_2 emissions in the Energy supply sector are distributed as indirect emissions to the other sectors

[59] The total does not include the Energy supply (CO_2-related) sector, as these emissions are included in the other sectors as indirect emissions.

[60] This assumption is reasonable, as the change is below 1% (6,5 Mtonneson) for EU10 between the two scenarios according to EEA (2005a).

Mtonnes CO_{2eq}	**Baseline scenario 2010** **Emissions**	**Baseline scenario 2010** **Change from base year in baseline scenario**	**Scenario 1, 2010** **Emissions**	**Scenario 1, 2010** **Change from base year in baseline scenario**
Energy supply (CO_2 emissions)[61]	1642	-1.3%	1588	-4.5%
Energy supply (non-CO_2 GHG emissions)	57	-25.0%	55	-27.0%
Fossil fuel extraction, transport and distribution	77	-37.9%	74	-40.3%
Industry	1653	-6.9%	1572	-11.4%
Transport	1016	29.8%	1016	29.8%
Households	872	-9.5%	842	-12.7%
Services	582	2.5%	562	-1.1%
Agriculture	507	-14.8%	500	-16.0%
Waste	100	-53.7%	101	-53.7%
Total[62]	4864	-4.7%	4722	-7.4%

Table 61 Emissions in baseline scenario and scenario 1 for EU25 in 2010. EU25 is the sum of EU15 and EU10. In scenario 1 it is assumed that no further measures will be implemented in EU10 than the ones already included in the baseline scenario for EU10 .

---

[61] The CO_2 emissions in the Energy supply sector are distributed as indirect emissions to the other sectors

[62] The total does not include the Energy supply (CO_2-related) sector, as these emissions are included in the other sectors as indirect emissions.

6.3. POLICIES AND MEASURES

Policies and measures are abbreviated as PAMs in this chapter.

A brief compilation was made of the PAMs described in The European Climate Change Programme – EU Action against Climate Change 2006 (below called EC Brochure), see Table . The information was proposed to form a basis for the detailed expert assessments, made by the project team for each respective sector.

All PAMs given in the EC Brochure are listed and summarised. However, more information can be found in the EC Brochure and further details can be found in the corresponding full texts of the PAMs (many of them can be downloaded from http://europa.eu).

The EC Brochure lists both existing and planned PAMs. Estimations have been made whether the PAMs are implemented (not at all, partly or fully) in the baseline scenario and scenario 1. Those PAMs considered either partly or not implemented in baseline scenario or scenario 1, could thus still be available for further reductions. Since scenario 1 is intended to include planned PAMs, most of the EC Brochure PAMs are considered included in scenario 1. Consequently, not many of these PAMs are considered available for further reductions.

For some PAMs in the EC brochure reduction potentials are given up to 2010. It should be noted that these potentials are calculated according to a business as usual scenario, which is not consistent with the baseline scenario used in this project. Furthermore, it is important to point out that the potentials are not completely addable. Adding them all together could lead to an overestimation of the potential.

PAM No	Short description of PAM	Sector	In scenario 0 (baseline)	In scenario 1	Potential by 2010 compared to the baseline, Mtonnes, [63], [64]		Comment
1	EU ETS				Min	Max	Potential depends on size of cap, included sectors etc.
2	CDM and JI						Not only domestic measures --> not considered in this project!
3	GHG monitoring						
4	Renewable electricity	Energy supply	Fully	Fully	100	125	
5	Biofuels	Transport	Partly	Partly	35	40	3,9% in existing baseline (target 5,75%)
6	Cogeneration	Energy supply	Not	Fully	22	42	
7	Biomass action plan	Energy supply	Not	Fully	36	48	
8	ALTENER	Energy supply	Partly	Partly			R&D programme
9	Energy performance of buildings	Energy use	Fully	Fully	20	20	
10	Energy labelling	Energy use	Partly	Fully	54	54	31 Mtonnes (existing) in baseline, 23 Mtonnes (planned) in scenario 1
11	Eco-design	Energy use	Not	Fully			
12	End-use efficiency and energy services	Energy use	Not	Fully	40	55	
13	Green paper	Energy use	Not	Fully			
14	IPPC, Bref on energy efficiency [65]	Energy use	Fully	Fully			
15	Motor challenge programme	Energy use	Fully	Fully			
16	SAVE	Energy use	Fully	Fully			
17	Sustainable Energy Europe	Energy use	Fully	Fully			
18	Green public pocurement	Energy use	Fully	Fully			

---

[63] Potential compared to the business as usual scenario used in the EC brochure

[64] Potential numbers are given for EU-15

[65] Bref = BAT (Best Available Technology) Reference Document

PAM No	Short description of PAM	Sector	In scenario 0 (baseline)	In scenario 1	Potential by 2010 compared to the baseline, Mtonnes, [63], [64]		Comment
19	Climate change awareness campaign	Energy use	Not	Fully			
20	CO_2 from new passenger cars	Transport	Partly	Partly	107	115	Not including the 120g/km target --> further potential. Assumption: not implemented in EEA and Primes (2005)
21	Transport shift from road to rail	Transport	Fully	Fully			
22	Charging of HDV	Transport	Fully	Fully			
23	Minimum taxation	Transport	Fully	Fully			
24	HFC in vehicles	Transport	Not	Not			After 2010 --> excluded from this study
25	STEER	Transport	Fully	Fully			
26	Thematic strategy transport	Transport	Not	Fully			
27	Flourinated GHG	Industry	Fully	Fully	23	23	
28	IPPC industry and agriculture	Industry	Fully	Fully			
29	Methane from land fills	Industry	Fully	Fully	41	41	
30	Thematic strategy waste	Industry	Not	Fully			
31	CC in EU Rural Development Policy	Agriculture, forestry					Carbon sequestration --> not of interest for this project.
32	Energy crops	Transp &en	Fully	Fully			
33	Reduction of N_2O in soils	Agriculture, forestry	Partly	Fully	10	10	
34	EU Framework Programmes						R&D programme
35	LIFE						R&D programme
36	EU Structural and Cohension Funds						R&D programme
				SUM [66]	488	573	

Table 62 Compilation of Policies and measures presented in the EC brochure. The European Climate Change Programme – EU Action against Climate Change 2006. The compilation refers to EU15 and the potentials are given compared to a business as usual scenario. The table also shows estimations of degrees of implementation for each PAM in scenario 0 and scenario 1, i.e. whether they are fulfilled fully, partly or not at all. All measures and potentials given above aren't necessary addable. Adding them together might lead to an overestimation of the potential.

---

[66] All measures and potentials given above aren't necessary addable. Adding them together might lead to an overestimation of the potential.

6.4. CONCLUSIONS

In scenario 0 the total emissions have decreased by 4.7% compared to base year emissions (EU25). In the scenario 1 the total emissions have decreased by 7.4% (EU25). For EU25 a further reduction of 14 Mtonnes CO_2 compared to the scenario 1 is necessary to reach the Kyoto agreement (slightly less than 8% compared to base year because Poland and Hungary only need to reduce their emissions by 6% and Malta and Cyprus do not have any obligation in the Kyoto agreement (EEA 2005a)). For EU15 a further reduction of 160 Mtonnes CO_2 compared to the scenario 1 is necessary to reach the Kyoto agreement of 8% reduction relative to the base year, see Table 63.

Mtonnes CO_{2eq}	**Base year (1990)**	**Scenario 1 (2010)**	**Kyoto target[67] (average 2008-2012)**	**Diff Scenario 1 – Kyoto**
EU15	4075	3909	3749	160
EU10	1027	813	959	-146
EU25	5102	4722	4708	14

Table 63 Emission levels for EU15, EU10 and EU25.

---

[67] The calculations of the Kyoto targets are based on -8% target for all EU25 countries except Poland and Hungary, which have Kyoto targets of -6%. Malta and Cyprus do not have Kyoto commitments, but as their emissions account for 0,2% only, they are disregarded in the table.

7. PATHWAYS TO “KYOTO”

7.1. COMPARISON OF COST-EFFECTIVENESS BETWEEN AND WITHIN SECTORS (INFRAS)

Reduction potentials

The following figure gives an overview of the emission reduction potentials by sector resulting from contributions of a long list of individual measures (see annex to chapter 7.3). Out of the total of 650 Mtonnes/a the energy supply sector accounts for almost 50% of the total reduction potential, and also the industry shows a considerable share (22%). The road transport could contribute about 13%, as much as the remaining sectors together (household, services, waste). The contributions of the agricultural and forestry sectors are negligible. Particularly, within the energy supply sector the biggest potentials are provided by a few singular measures with potentials of >10 Mtonnes/a: the measure with the biggest potential by far is NGCC (natural gas combined cycle, 127 Mtonnes/a); but also CHP (combined heat and power production, 32 Mtonnes/a), biomass (15-65 Mtonnes/a – depending on the cost levels) and CO_2 removal and storage with 25 Mtonnes/a have considerable reduction potentials. In the industry it is the chemical industry (nitric acid industrial processes) with a noteworthy potential of ca. 16 Mtonnes/a. The other potentials result from a multitude of contributors, which nevertheless sum up to a considerable amount. Also in the other sectors the contributions are much more split up among many singular measures. Some of the important measures are e.g retrofitting houses/roof insulations with 9 Mtonnes/a, and Building Energy Management Systems (BEMS, space heating and cooling) with 8 Mtonnes/a.

EMISSION REDUCTION POTENTIALS BY SECTOR (TOTAL 650 MTONNES CO2EQ/A)

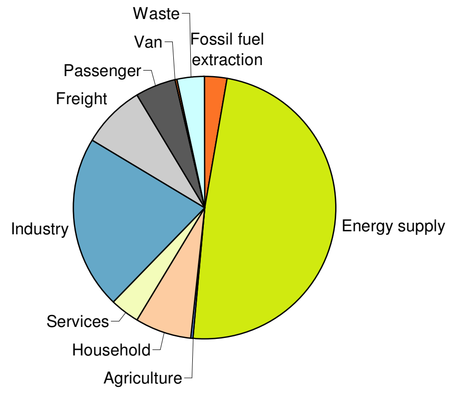


Figure 30 Distribution of the emission reduction potentials by sector (total: ca. 650 Mtonnes CO_{2eq}/a in the periode 2008/2012).

Cost effectiveness

The reduction potential alone is of limited interest without considering the associated costs. What matters is the cost effectiveness of the different measures in particular of those sectors with big potentials. Therefore the following figures show the MAC curves of the different sectors. They indicate that the energy supply and industry not only have the biggest reduction potentials, they also have big potentials at comparatively low costs or even at negative costs. In the energy supply sector ca. 200 Mtonnes/a are reduceable at costs of <16 € / t CO_{2eq} (mainly due to NGCC) while in the industry another 100 Mtonnes/a might be reduced at similar or lower costs, some 50% of them even at negative costs. Comparing the "profitability" of all measures and of all sectors, ca. 200 Mtonnes could be reduced at <0 € / t CO_{2eq} the industry being the main contributor (with ca 90 Mtonnes) at negative or zero costs; the other sectors could contribute as follows at <= 0 € / t CO_{2eq}: household: 30 Mtonnes/a, energy supply: 23 Mtonnes/a, Services 13 Mtonnes/a, fossil fuel extraction: 5 Mtonnes/a and transport: 38 Mtonnes/a.

The transport sector overall shows a reduction potential of ca 83 Mtonnes (passenger cars: 32 Mtonnes, freight: 49 Mtonnes, and van: 2 Mtonnes). As mentioned above, 38 out of the 83 Mtonnes/a (= ca. 45%) are achievable at <0 €/t, some additional 35% at costs up to 200 €/t and the rest (ca 20%) at higher costs. What has to be noticed though is the fact that some of the "profitable" reductions in the transport sector are due to non-technical, behavioural measures (e.g. freight logistics, eco driving). Their real total costs may be higher if transaction costs (e.g.

further incentives, campaigns, monitoring etc.) would have to be taken into account. Other transport measures with considerable contributions (like weight limit increase to 44t or even 60t, with a sum of 15 Mtonnes/a) may be only theoretically feasible within the timeframe 2008/2012. If we hence would remove these measures from the list of realistically available measures, the transport reduction potential would be reduced by about 35% or from 83 to 53 Mtonnes/a, and the costs for the measures would increase. The marginal abatement costs of the transport sector then certainly would be considerably moved up relative to e.g. energy supply and industry, and many more measures from industry and energy supply would be more effective than measures in the transport sector to reach a given target such as Kyoto.

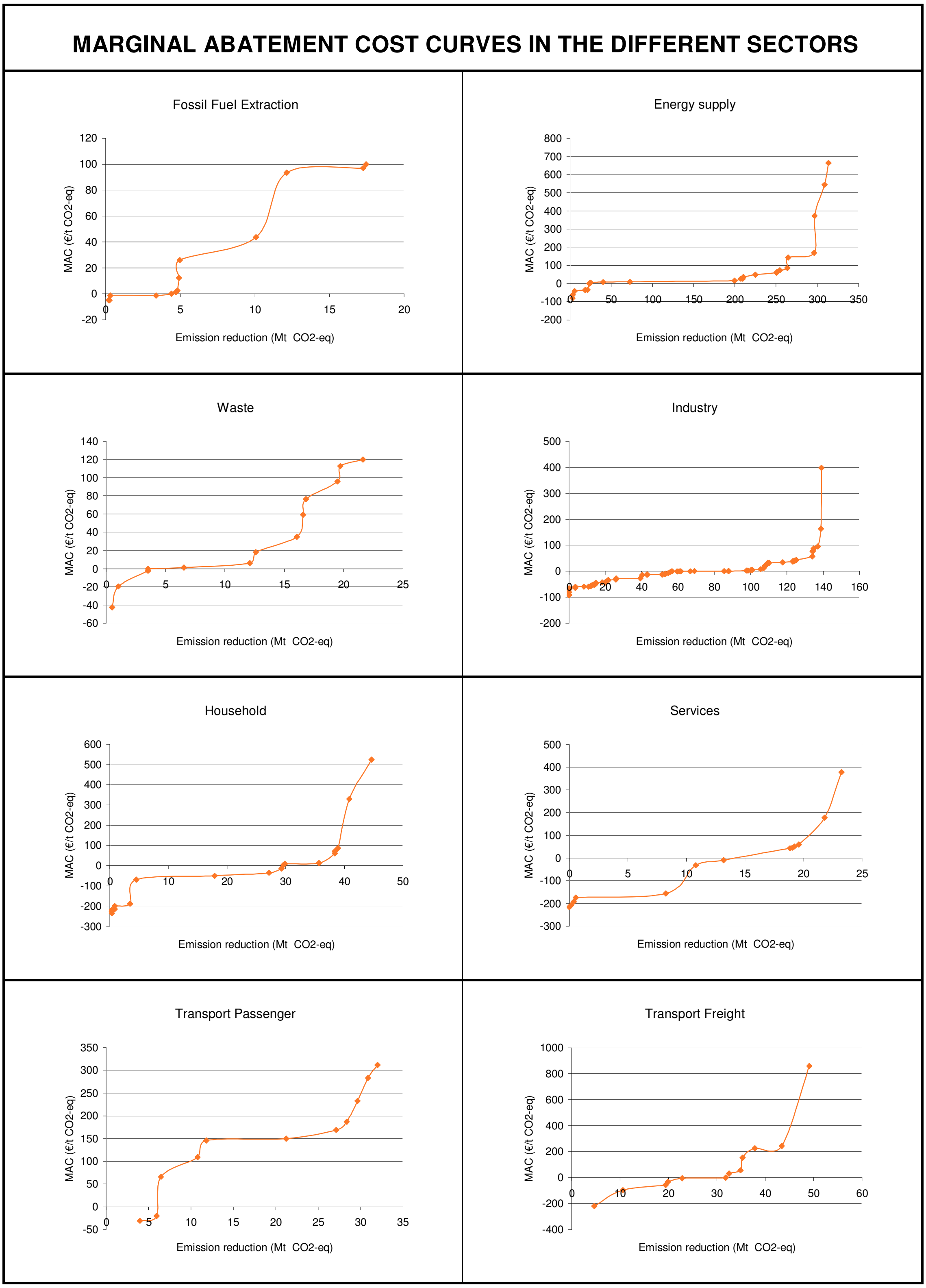


Figure 31 The MAC between different sectors show that a considerable amount of the reduction potential could be implemented at negative or low costs. This hold in particular for the sector energy supply and industry.

7.2. OPTIMAL PATHWAYS (IVL)

The aim of this analysis is to evaluate the optimal measures for achieving the Kyoto target. By optimal we mean most cost-effective. Thereby the cheapest options are equal to the most optimal ones. The basis for the analysis have been an aggregate MAC curve for all sectors and emission data for the base year (1990), scenario 1 (2010) and the Kyoto target (2012).

It is important to note that there are large uncertainties in the calculations, due to the various assumptions made in the project, the fact that all measures are not necessarily addable (they might be alternatives to each other or influence each others' potentials), the scenario definitions etc. Therefore, the analyses below should be taken as qualitative discussions, not exact quantitative statements.

7.2.1. GAP TO KYOTO

Table 64, summarises emission levels for EU15, EU10 and EU25 in base year (1990) and scenario 1 (2010). The Kyoto targets (average 2008-2012) as well as the difference between scenario 1 and the Kyoto target are also shown. As presented in the table, the reduction left to reach the Kyoto target is only 14 Mtonnes for EU25. This is mainly due to extensive reductions made in EU10 from the base year. The gap for EU15 will still be 160 Mtonnes CO_2. It should also be mentioned that this forecast is based on the gap between scenario 1 and Kyoto, and is therefore based on the assumption that all policies and measures, planned in scenario 1 have been implemented. In reality, the gap to Kyoto could be higher.

Mtonnes CO_{2eq}	**Base year (1990)**	**Scenario 1 (2010)**	**Kyoto target[68] (average 2008-2012)**	**Diff Scenario 1 – Kyoto**
EU15	4075	3909	3749	160
EU10	1027	813	959	-146
EU25	5102	4722	4708	14

Table 64 Emission levels for EU15, EU10 and EU25.

---

[68] The calculations of the Kyoto targets are based on -8% target for all EU25 countries except Poland and Hungary, which have Kyoto targets of -6%. Malta and Cyprus do not have Kyoto commitments, but their emissions account for 0,2% only (EEA 2005a).

7.2.2. AGGREGATE MAC-CURVE

The task of this section is to evaluate optimal pathways to reach the Kyoto beyond the planned policies and measures assumed to be implemented in scenario 1. Consequently, the task is to seek the optimal emission reduction measures to decrease the EU25 emissions by 14 Mtonnes. This has been done by compiling an aggregate MAC curve for EU25, see Figure 32. . This analysis is complemented by some qualitative considerations regarding the optimal pathway to reach the Kyoto target for EU15.[69]

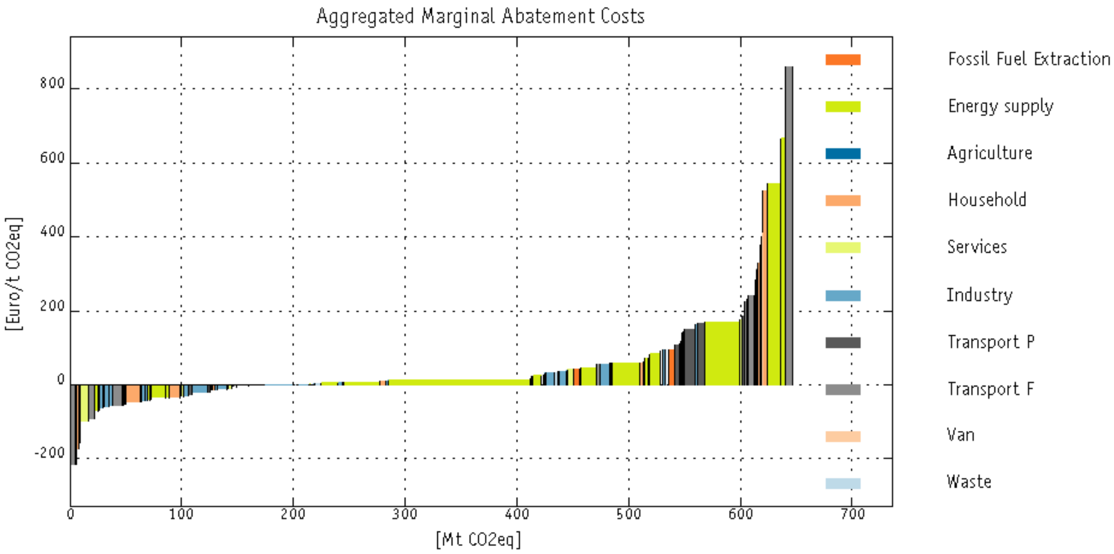


Figure 32 Aggregate MAC curve for all measures available for further reduction beyond scenario 1. The various colours represent different sectors, as shown to the right in the figure.

A comprehensive table showing all MAC data (almost 200 measures), sorted by marginal abatement cost, is shown in the annex to chapter 6.3. That table and the aggregate MAC curve in Figure 32, clearly show that the Kyoto target can be reached by "profitable" measures (measures having negative costs) alone. This result holds for EU25 as well as for EU15. Table 65 below lists these profitable measures, enough to fulfil the Kyoto target for EU25.

---

[69] Since the achievement of the Kyoto target for EU 15 is still of political relevance.

Measure	**Sector**	**Annual em. red. pot. [Mtonnes CO_{2eq}]**	**MAC [euro/ton CO_{2eq}]**	**Acc. annual em. red. pot. [Mtonnes CO_{2eq}]**
Energy efficient TV and video equipment	Household	0.4	-235	0.4
Freight logistic optimisation	Freight	4.7	-219	5.1
Efficient lightning: Best Practice (fully implemented)	Household	0.5	-216	5.5
Efficient space cooling equipment	Services	0.1	-208	5.7
Efficient lighting: Best Practice level 1	Services	0.2	-193	5.9
Miscellaneous options (moderate costs tranche)	Household	2.6	-189	8.5
Very efficient lighting: Best Practice level 2	Services	0.2	-175	8.7
Building Energy Management Systems (BEMS): space heating and cooling	Services	7.7	-156	16.4

Table 65 Compilation of the cheapest measures available for emission reductions to reach the Kyoto target (timeframe 2008-2012). Em. red. = emission reduction, MAC = marginal abatement cost, Acc. em. red. = Accumulated emission reduction.

As shown in Table 65, the measures are mainly **energy efficiency improvement (insulation, efficient equipment etc.) in the households** (25%) **and services sectors** (42%). However, there is also one important measure in the transport sector, i.e. **freight logistic optimisation** (33%). For EU15 the optimal pathway to reach the Kyoto target consists of further measures in the industry and energy supply sector.

MAC curve based on “measurable and monitorable” measures only

Some of the measures discussed in the previous chapters and underlying the aggregate MAC curve depicted in Figure 32 may be interpreted as “non-measurable” and/or “non-monitorable”. This may be the case for behavioural measures where it is difficult to determine in a transparent and reliable manner the level of implementation of a measure and in particular the effect of the measure in terms of emission reduction. However, for many measures there may well be empirical indicators from which an effect can be deferred. Therefore, for creating a MAC curve based on “measurable and monitorable” measures only, we require a strong behavioural component for excluding a measure from the list. If empirical indicators (e.g. sale figures of certain equipment) are available, we term the measure as “measurable” and “monitorable”. Examples: We assume “low rolling resistance tyres” or “low viscosity lubricants” to be “measurable and monitorable”, even if requires some sort of standard or labelling for these equipments; similarly in the case of housing (wall insulation, efficient lightning, TV equipment etc.). Bases on these considerations we exclude the following measures, most of them belonging to the transport sector (the figures indicate the reduction potential in Mt CO_2-eq and the MAC in €/t CO_2-eq):

› Freight logistic optimisation (5 Mt; -219 €/t CO_2-eq)
› Driver training HDV (3 Mt; -5 €/t CO_2-eq)
› Fuel efficient driving (4 Mt, -31 €/t CO_2-eq)
› Tyre pressure monitoring systems (2 Mt; -20 €/t CO_2-eq).

In the non-transport sectors only the “miscellaneous” measures (mainly household) are interpreted as non-measurable, with a limited reduction potential though (some 3 Mt).

This indicates that these “non-measurable” measures are responsible for a very limited amount of the total potential only (some 15-20 Mt out of the 650 Mt of all measures). Therefore the aggregate MAC curve with “measurable and monitorable” measures only (see Figure 33) looks very similar to the original MAC curve based on the list of all measures (Figure 32).

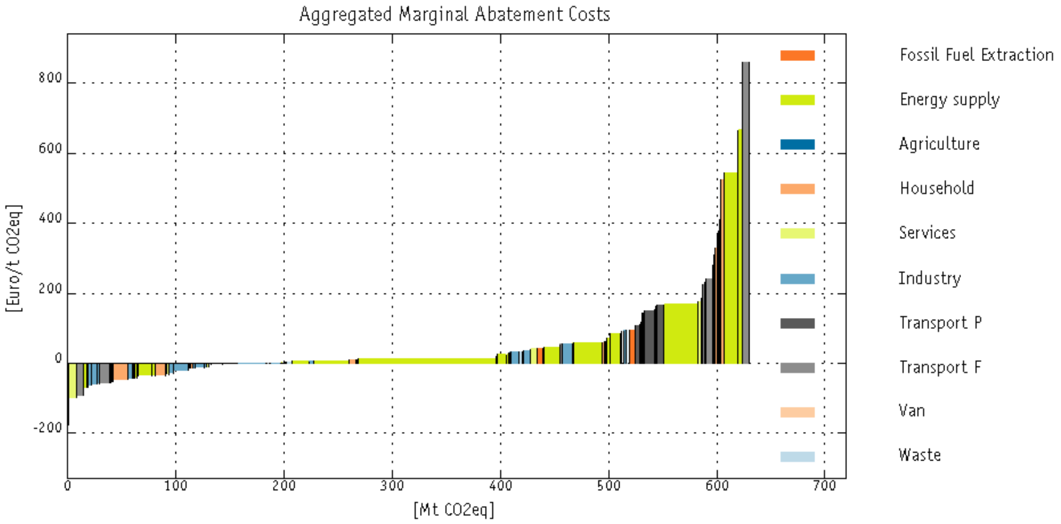


Figure 33 Aggregate MAC curve for measurable and monitorable measures available for further reduction beyond scenario 1. The various colours represent different sectors, as shown to the right in the figure.

7.2.3. STRICTER TARGETS

As shown in the table in the annex to chapter 6.3 (all MAC data), emission reductions up to about 165 Mtonnes can be reached by profitable measures in EU 25 beyond scenario 1. This corresponds to an emission reduction of just over 10% compared to the base year. These measures are mainly in the **industry** (34%), **freight** (19%), **households** (18%), and **energy supply** (13%) sectors. The industry related measures are made up of many very diverse measures, and are difficult to classify. Added measures in the freight transport sector are increased weight limit, improved engines, driver training and reduced rolling resistance. In the households sector the measures are mainly energy efficiency measures (insulation, efficient equipment etc.). The measures in the energy supply sector constitute measures in the refineries as well as biomass combined heat and power production.

Another 130 to 140 Mtonnes emission reduction can be reached by adding measures with zero cost. These measures have the focus in **the industry sector** and, again, consist of many diverse measures.

Measure	**Sector**	**Annual em. red. pot. [Mtonnes CO_{2eq}]**	**MAC [euro/ton CO_{2eq}]**	**Acc. annual em. red. pot. [Mtonnes CO_{2eq}]**
Increased weight limit (44t)	Freight	5.9	-97	5.9
Refineries: Reflux overhead vapour recompression (distillation)	Energy supply	3.0	-80	8.9
Miscellaneous I (Low cost tranche)	Industry	3.4	-64	12.3
Miscellaneous I (Low cost tranche)	Industry	4.8	-59	17.1
Increased weight limit (60t)	Freight	8.8	-58	25.9
Retrofit houses: wall insulation	Household	13.3	-51	39.2
Food, beverages and tobacco – micellaneuous II (High cos t tranche)	Industry	3.5	-42	42.7
Biomass (waste) 3b: Heat only on solid biomass	Energy supply	12.7	-36	55.4
Refineries: Miscellaneous I (Low cost tranche)	Energy supply	3.0	-35	58.4
Retrofit houses: roof insulation	Household	9.3	-35	67.7
Miscellaneous II (High cost tranche)	Industry	4.1	-32	71.8
Fuel efficient driving	Passenger	4.0	-31	75.8
Miscellaneous II (High cost tranche)	Industry	13.5	-27	89.3
Miscellaneous II (High cost tranche)	Industry	8.3	-13	97.6
Driver training at HDV	Freight	2.9	-5	100.5
Reduced rolling resistance	Freight	9.0	-3	109.5
Coal mining degas ification (low and medium recovery rate) Coal mining	Fossil fuel extraction	3.1	-1	112.6
Oxidation of HFC-23	Industry	5.3	0	117.9
Industrial processes Nitric acid	Industry	16.5	0	134.4

Table 66 Compilation of further measures available for emission reductions to reach the Kyoto target with a reduction potential > 2.5 Mtonnes CO2. Em. red. = emission reduction, MAC = marginal abatement cost, Acc. em. red. = Accumulated emission reduction.

7.2.4. DISCUSSION

To reach the Kyoto target of approximately 8% emission reduction in the EU 25, another 14 Mtonnes CO_2 equivalents have to be reduced after implementing all planned measures in scenario 1 (for EU15 the corresponding figure is 160 Mtonnes CO_2). As concluded in the separate sub-chapters above, based on the calculations, prerequisites and assumptions made in this project, these 14 Mtonnes emission reductions can be reached at negative costs. The measures are mainly **energy efficiency improvement (insulation, efficient equipment etc.) in the households** (25%) **and services sectors** (42%), but also **logistic optimisation of freight transport** (33%). The accumulated profit from these measures would, according to the calculations, prerequisites and assumptions made in this project, be around 3 M€, but this figure is associated with large uncertainties!

The analysis also shows that all measures having negative costs, sum up to a reduction potential (beyond S1) of 165 Mtonnes CO_2 equivalents. These measures are mainly related to the industry, freight, households and energy supply sectors. Another 35 Mtonnes emission reduction can be reached by measures having roughly zero cost, almost solely measures in the industry sector.

From Figure 32 it can be concluded that the costs rise only slowly up to about 400 Mtonnes accumulated emission reduction, landing at a marginal abatement cost of about 25 €/ton CO_2 eq. Thereafter, the costs increase steeper until 500 Mtonnes CO_2 eq (cost approximately 70 €/ton). The first really sharp increase in costs occurs between 600 and 650 Mtonnes accumulated emission reduction, where the cost increases from approximately 175 €/ton up to almost 900 €/ton at an accumulated potential of 650 Mtonnes. The most expensive costs are found in various sectors as shown in the table of the Annex to chapter 6.3.

Finally, it can be stated from the table in the annex to chapter 6.3, that the breakeven point between costs and profits is reached at an accumulated emission reduction potential of approximately 525 Mtonnes CO_2 equivalents, with the calculations, prerequisites and assumptions made in this project. At this point the sum of the total accumulated marginal abatement costs (positive as well as negative costs) equals zero.

7.3. SENSITIVITY ANALYSIS (INFRAS)

7.3.1. LIMITATIONS

While numerical sensitivity analysis is not possible within the scope of this project (with the exception of PC and HDV in Transport) it is important to discuss the sensitivity of the results and conclusion qualitatively. The most relevant parameters for such considerations are:

1. Energy prices[70], which have risen dramatically since Blok (2001), especially during the past 2 years,
2. Degrees of implementation (DoI) of PAMs , or, respectively reduction potentials of PAMs,
3. Cost; in particular investment cost of reduction measures,
4. Social discount rate.

The sensitivity discussion aims primarily at information regarding changes of

- the overall net cost of the Kyoto target fulfilment, and
- the mix of measures and sectors involved in the emission reduction induced by changes in each one of the above parameters.

7.3.2. DEPENDENCY ON SHAPE OF MAC CURVE

It seems important to make the following general observations (See the figure below):

- **Changes in the degrees of implementation** (DoI) will tend to shift the MAC curve horizontally: If an overestimation of DoI is corrected, the MAC curve shifts horizontally to the left. If the curve near the target fulfilment is flat, this will not change much in the costs of reaching the target, but if it is steep, then a shift to the left will lead to measures with significantly higher cost for target fulfilment. As a result, the overall cost of meeting the target rises accordingly. The same shifts due to changes in DoI will change the mix of measures involved: If near the target line one or more measures deliver large reduction contributions, then the mix of measures will not change much. On the other hand, if many different measures with small reductions are located near the target line, the mix of measures reacts sensitively.
- **Changes in MACs** of measures shift the MAC curve vertically. If these are systematic changes, for example due to energy price increases, the curve shifts upward, more or less as a whole. In such cases the cost of meeting the target line is represented by the area under the original and the shifted MAC curve. Such vertical changes of the curve do not influence the

---

[70] Note that rising energy prices reduce the net costs and MACs of reduction measures, due to higher savings on the benefit side.

mix of measures sensitively. However when the cost of only one specific measure changes, this may change the mix of measures involved in fulfilling the target cost effectively.

STRUCTURE OF THE MAC CURVES

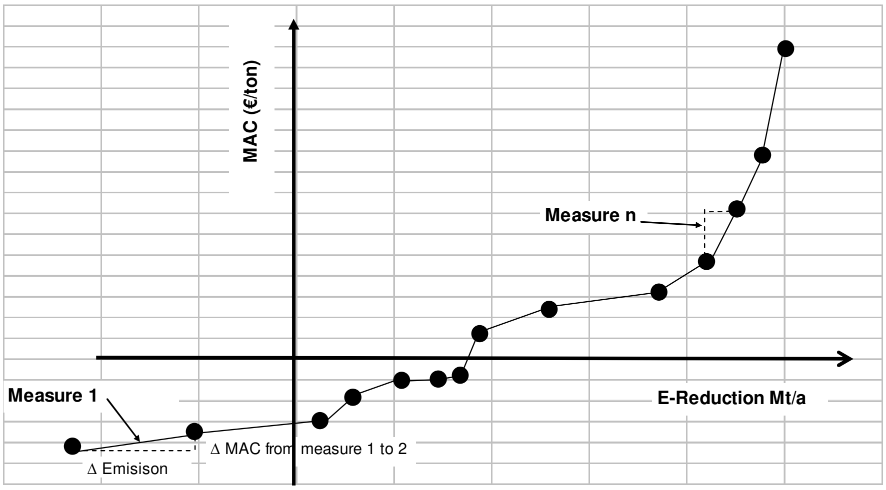


Figure 34 The shape of the MAC curve near the target of fulfilment (TF) has a major influence on the sensitivities to changes in degrees of implementation (DoI) in general: If the curve is flat and if near the target measures with large reduction contributions appear, changes in the DoI of measure have a small influence on the mix of PAMs involved On the other hand, if near the point of target fulfilment (TF) many PAMs with small reduction contributions are located on the MAC curve, then the mix of measures changes significantly, while when PAMs with large contributions are located near TF, then the mix changes insensitively.

7.3.3. ENERGY PRICES

Since the Blok study (2001) energy prices have more than doubled[71]. This generally increases the benefits stemming from the energy savings or from the substitution of fossil fuel energy by other forms, such as renewables.

Some quantitative sensitivity analyses regarding changes in energy prices have been performed in the transport sector. The results are shown in the figures below.

The rise in diesel fuel price from 30 to 41 c/l leads to a decrease in the MACs in the HDV sector of about 50€/t on average. Integrated over the amount of emission reduction of the HDV sector (some 32 MTONNES/a), this corresponds to a lowering of the overall costs of all meas-

---

[71] In the Blok study an oil price of some 25€/bbl seems to have been assumed. In our base case analyses we used an oil price of 36/bbl, but today's prices are even higher. The sensitivity analysis carried out in the transport sector used a sensitivity case with 50€/bbl

ures of some 1.5 Bill €. This is indeed a sensitive reaction, making GHG emission reductions more profitable.

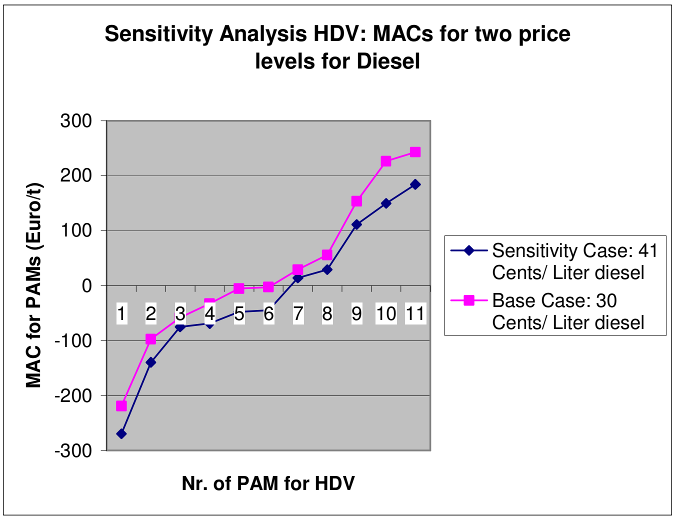


Figure 35 Sensitivity of MAC in the HDV sector due to energy price increases. The base case (30 cents/liter of diesel) corresponds to an oil price of about 36 €/bbl, and the sensitivity case to 50 c/l. The average increase in the MAC for HDV measures is around 50 €/t

The figure below shows similar results for passenger cars. Again, the MAC difference between the 36 €/bbl base case and the 50€/bbl sensitivity case is (at least) 50€/t of GHG reduction. For a more detailed discussion of the reliability of the results of this sensitivity analysis, see chapter 5.1.

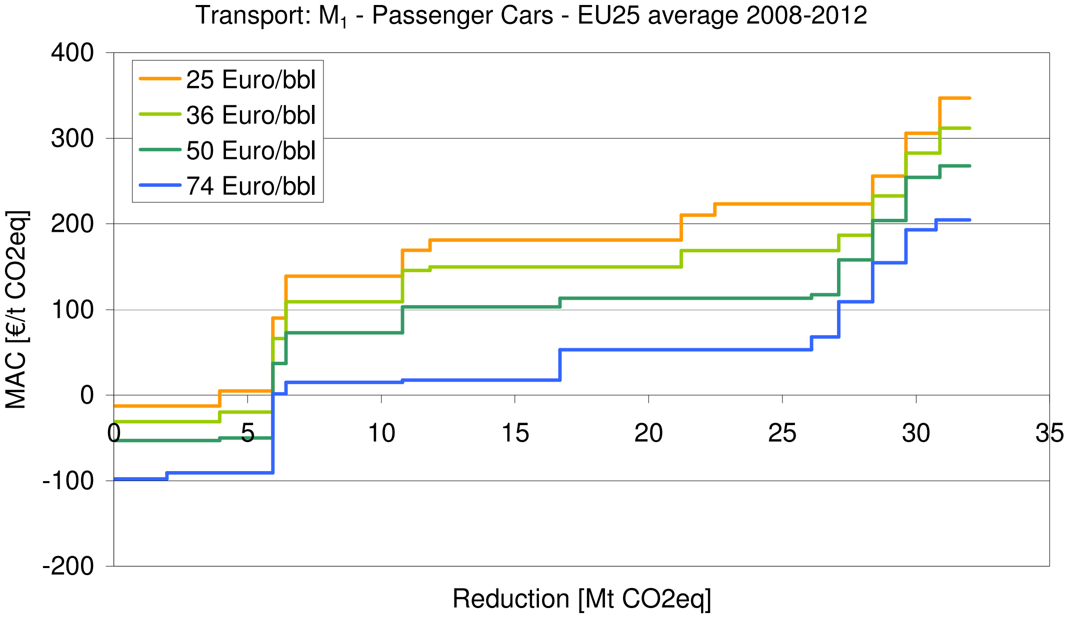


Figure 36 MAC curves for vans. Reduction potentials are estimated as average reductions in the period 2008-2012 in the EU25.

7.3.4. EFFECT OF NOT MEETING PRE-2010 POLICY TARGETS

Existing polices included in the baseline scenario are:

› the agreement between the European Commission and the car industry (ACEA/JAMA/KAMA) on their voluntary commitment to reduce average new car CO_2-emissions (on the type approval test) to 140 g/km in 2008/9, and

› the EU Biofuels Directive aiming at a share of biofuels in transport fuel use of 5.75% in 2010.

Both policies are defined in such a way that it can not be guaranteed that the targets are met. It therefore makes sense to include in the sensitivity analysis some scenario analysis exploring the consequences of a situation in which the above specified policy targets are not met in their respective target years.

Effects of not meeting the 140 g/km target in 2008/9

Scenario 1 assumes that the 140 g/km goal as set in the voluntary commitments of ACEA, JAMA and KAMA is met in 2008 resp. 2009. However, recent results from the monitoring of progress made under these voluntary agreements[72] indicate that the target are no longer likely to be met. If that is the case then the step towards a new vehicle sales average of 120 g/km in 2012 will require additional efforts to compensate the gap between 140 g/km and the final level reached in 2008/9. In this paragraph the costs and CO_2-reduction potential associated with these additional efforts are analysed.

Table 67 presents estimates of the additional CO_2-emissions that occur in EU-25 in the 2008-2012 period when the 2009 sales averaged CO_2-emission of new vehicles sold in Europe reaches a level of 145, 150, resp. 155 g/km. The calculations are made relative to a baseline TREMOVE scenario, which assumes that the Type Approval CO_2-emission level reaches 140 g/km in 2009 and further reduces to 138 g/km in 2012. For the alternative scenarios it is assumed that in 2009 a new vehicle Type Approval CO_2-emission level of 145, 150, resp. 155 g/km is reached. For the 2009-2012 period a similar 2 g/km reduction is assumed for the 2009-2012 period.

additional TTW CO2-emission EU25

2009 sales average	**2008**	**2009**	**2010**	**2011**	**2012**	**average**	
145 g/km	4,0	5,5	6,7	8,1	9,2	6,7	Mtonne/y
150 g/km	7,6	10,6	13,3	16,2	18,8	13,3	Mtonne/y
155 g/km	9,9	14,3	18,4	22,5	26,2	18,2	Mtonne/y

additional WTW CO2-emission EU25

2009 sales average	**2008**	**2009**	**2010**	**2011**	**2012**	**average**	
145 g/km	4,7	6,5	8,0	9,5	10,8	7,9	Mtonne/y
150 g/km	9,0	12,5	15,7	19,1	22,3	15,7	Mtonne/y
155 g/km	11,7	16,9	21,8	26,6	31,0	21,6	Mtonne/y

Table 67 Additional tank-to-wheel and well-to-wheel emissions in EU-25 in the 2008-2012 period resulting from not meeting the 140 g/km target of the voluntary commitments compared to a baseline scenario in which 140 g/km is met in 2009.

The values for a gap of 5, 10 or 15 g/km as indicated in Table 67 are significantly higher than the annual reductions obtained by going form 140 g/km in 2009 to 120 g/km in 2012. This has two reasons. First of all the 5, 10 or 15 g/km gap compared to the baseline applies to all new vehicles sold between 2008 and 2012. In the scenario in which CO_2-emissions are reduced to 120 g/km in 2012 the sales average for new vehicles decreases gradually between 2008 and 2012. Furthermore it has been assumed for the scenarios in which the 140 g/km is not met that the sales averaged CO_2-emission already start to deviate from the baseline in 2005. The fleet in

---

[72] COM(2006) 463

the years 2008 – 2012 thus also contains vehicles built before 2008 that already emit more than in the baseline.

Assuming a post-2009 policy measure to reduce sales average CO_2-emissions to 120 g/km in 2012 additional vehicle costs occur[73] if the 2008/9 target of 140 g/km is not met. Table 68 shows calculations of the retail price increase and additional societal costs (retail price minus taxes) occurring in the 2002-2008 period in the case the 2008/9 sales average CO_2-emissions reach 140, 145, 150, resp. 155 g/km, as well as the additional retail price increase and additional societal costs for going from that level to 120 g/km in 2012. Based on the societal costs and the fuel cost savings associated with an additional CO_2-reduction of 5, 10 or 15 g/km also the CO_2-abatament costs are calculated. These results have been generated using the models developed for (TNO 2006).

	retail price increase			
2008/9 average [g/km]	2002 - 2008 [€/veh.]	2012 average [g/km]	2009 - 2012 [€/veh.]	add. costs [€/veh.]
140	1198	120	2403	--
145	917	120	2717	314
150	686	120	2985	582
155	495	120	3219	816

	additional societal costs				CO2-abatement costs			
2008/9 average	2002 - 2008	2012 average	2009 - 2012	add. costs	@ fuel costs = 0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
[g/km]	[€/veh.]	[g/km]	[€/veh.]	[€/veh.]	[€/tonne]	[€/tonne]	[€/tonne]	[€/tonne]
140	965	120	1936	--	--	--	--	--
145	739	120	2189	253	117	94	65	16
150	553	120	2405	469	105	81	53	4
155	399	120	2593	657	94	71	42	-7

Table 68 Assessment of additional costs in the 2009-2012 period if the 2008/9 target of 140 g/km is not met. The tables present the additional retail price increase resp. societal costs (retail price minus taxes) for reaching a 2008/9 CO_2-emission level between 140 and 155 g/km and for going from that level to 120 g/km in 2012, and also shows the additional compared to the baseline situation in which 140 g/km is reached in 2008/9. Based on these additional costs CO_2-abatement costs can be calculated.

Compared to the baseline situation the additional costs presented in Table 68 are not made in the 2002-2008 period but instead in the 2009-2012 period. If the target of the voluntary commitments is not met it is justified to attribute these costs to a new CO_2-policy for cars implemented for the period after 2008/9.

---

[73] Compared to a baseline situation in which 140 g/km is reached in 2008/9 and 120 g/km in 2012.

The consequence of not meeting the 140 g/km target in the baseline for this study would be that an additional WTW CO_2-reduction of between 8 and 22 Mtonne/y would have to be realised in order to reach the Kyoto target. This value adds to the "Kyoto-gap" of 14 Mtonne/y as mentioned in Table 64. The size of the additional gap indicates that the voluntary commitments play a significant role in reaching the Kyoto targets for EU-25. The fact that this reduction is not realised in the baseline also adds an additional step[74] to the overall cost curve (as presented in Figure 32) with a width (EU-25 reduction potential) equivalent to the required additional CO_2-reduction of between 8 and 22 Mtonne/y and CO_2-abatement costs as given in Table 68 (between 70 and 120 €/tonne for oil price values between 25 and 36 €/bbl). In a least cost approach, however, this reduction potential will not be used as the additional gap for reaching the Kyoto target can be bridged with available other measures (mainly in other sectors) with negative CO_2-abatement costs.

Effects of not meeting the 5.75% target of the Biofuels Directive

As discussed in section 5.1.8 an increased use of 1% biofuels in passenger cars results in a WTW CO_2-reduction of 3.5 Mtonnes/y. For light-duty commercial vehicles 1% additional biofuels use yields a CO_2-reduction of 0.4 Mtonne/y (see e.g. section 5.1.11), while for HD-vehicles 1% additional biofuels use would result in about 1.8 Mtonne/y CO_2-reduction (see section 5.2.12). The total reduction of increasing the share of biofuels by 1% is thus around 5.7 Mtonne/y in the 2008-2012 period. The other way around, not meeting the 2010 target of 5.75 % by 1% results in 5.7 Mtonne/y additional emissions compared to the baseline (scenario 1).

In this study and for the given blending percentages the CO_2-abatement costs for biofuels are assumed independent of the volume used (and the % blended) and range from 223 €/tonne for an oil price of 25 €/bbl to 17 €/tonne for an oil price of 74 €/bbl (see sections 5.1.8 and 5.1.11).

Not meeting the 2010 target of 5.75% biofuels (as set by the EU Biofuels Directive) by *n* % thus leads to an additional gap for meeting the EU-25 Kyoto target of *n* x 5.7 Mtonnes/y. Similar to the case of not meeting the 140 g/km target, as discussed above, in a least cost approach this gap will not be bridged by the use of additional biofuels, but by other available measures (see cost curve presented in Figure 32) with negative CO_2-abatement costs.

---

[74] I.e. technical measures that can be applied to reduce passenger car CO_2-emissions from 155, 150, resp. 145 g/km to 140 g/km.

Conclusion

From the above analysis it can be concluded that not meeting the targets set by the voluntary commitments and the Biofuels Directive does significantly increase the EU-25 CO_2-reduction target compared to the 14 Mtonne/y value estimated for Scenario 1. The total gap, however, always remains smaller than the total reduction potential that can be achieved by combining all available measures in various sectors (i.e. measures that are not used in Scenario 1) that have negative CO_2-abatament costs.

7.3.5. SOCIAL DISCOUNT RATE

No quantitative sensitivity analyses could be carried out on the effects of different discount rates[75]. Generally speaking, a rise in the social discount rate lowers the future benefits (e.g. from energy savings) of an investment in GHG reduction. The result is a rise in the MACs. This effect is more important for investments with long lifetimes (housing, power plants) than in industrial investments in industry, or in a more expensive car buy.

It should be noted that a social discount rate of 4%/a (as Blok used it as the base case) seems rather conservative. A lower rate would be more in favour of longer term investments, in accordance with principles of sustainable development. On the other hand it is reasonable that enterprises use higher discount rates to assess their investments solely from a business standpoint, requiring shorter payback periods. The perspective that is relevant for this project, however is rather one of overall and longterm economics.

7.3.6. INVESTMENT COST AND LIFETIME OF INVESTMENTS

If investment cost rise, this has the same effect as a lowering of the social discount rate: The cost occurring today become more important, relative to the future benefits of the investment. This raises net MAC cost.

A semi quantitative analysis shows that the sensitivity of the MACs of PAMs is generally higher for PAMs with short payback periods (e.g. PAMs in the industry with usual payback periods of 3-5 years) than for PAMs with longer periods (e.g. house insulation measures, or investments in hydro wind or solar energy).

---

[75] Calculations in this report, with data stemming from Blok (2001), are generally based on 4%/a.

7.4. LONG TERM IMPLICATIONS (INFRAS)

The terms of reference foresee that "implications of the different policies and measures on the longer term GHG reductions, beyond 2012 will be discussed qualitatively". Two different general aspects should be mentioned:

Lifetime- and replacement-cycles as key parameter for the rate for further GHG reductions

The dynamics of replacement of existing (old) facilities, or the speed of market penetration of new, more efficient technologies is the key parameter for such a discussion of the longer term implications. The related dynamic processes determine how fast or how slowly further emission reductions can be achieved after 2012 without harming desinvestments.

Limited implementation potentials up to 2010/ 2012

Based on the above it becomes important to point out that the time between the present (2006/07) and 2010 is indeed very short, compared to the time frames required for the full implementation of many measures (PAMs): A significant list of measures, technical and non-technical, are included in the PAMs of the transport and other sectors, which realistically begin only to be implemented in 2008, so that for 2010 only two to three years of implementation are available while the development to market maturity, rollout and market penetration of new technologies fulfilling strong emission targets such as 120 g/km could well take more than a decade. Even the rollout and full implementation of PAMs with presumably shorter implementation cycles, such as energy efficient driving programs, freight logistic systems or the introduc-tion of tyre pressure monitoring systems could take up five years or more.

This implies inherently low degrees of implementation until 2010 and 2012. However, continued implementation of these policies will lead to increasing emission reductions after 2012. It is expected that these effects could well more than double the impacts (in Mtonnes/a) of many measures in the course of time after 2012, for example up to 2020.

In the following we structure the different PAMs analysed in the foregoing chapters

- first into categories with (economically and technologically) long vs. PAMs with shorter implementation cycles; and
- into PAMs within the transport sectors vs. PAMs in other sectors.

In each of these categories technical as well as behavioural PAMs can be included.

GHG Reductions in the transport sector with short time delays

These are PAMS which can be introduced (to some degree) “immediately” or with relatively short time delays. This includes the increase of the percentage of biofuels in gasoline powered vehicles (M1, N1) even beyond the 10%-level[76]. In addition, a continued penetration of the use (over and above the level assumed for 2010/2012 in chapter 5) of such measures as low resistance tyres and low viscosity lubricants could further reduce GHG emissions relatively rapidly. Automatic tyre pressure monitoring systems are tied to the longer turnover time of the car fleet (some 8-10 years). Such measures are possible for N1 and M1 vehicles, as well the HDV subesctor. It might also be possible to intensify the implementation of the freight logistic system discussed in Chapter 5.2, leading to a more rapid realisation of the considerable reduction potentials.

It must be realised, however, that PAMs with rapid implementation potentials of only one to three years generally are already included in scenario PAM0+ or PAM1+ (See chapter 5.1 and 5.2), for example the “immediate” increase of biofuels before 2012 from 5.75% to 10%. It follows that the potentials to rapidly or immediately reduce GHG emissions in the transport sector have already been included in the scenarios of this report for 2012. The potential for rapid further reductions is therefore limited. The most significant additional potential (possibly up to 15 Mtonnes/a) could be the intensified implementaion of the freight logistic systems. Similar examples are the intensification of HDV-driver training and ecodriving. The constraints for these approaches are not technical, but rather institutional, behavioural and political.

GHG reductions in the transport sector with longer time delays

PAMs relating to the replacement of equipment and facilities with longer life time cycles (e.g. vehicle fleets, distribution infrastructures), or the introduction of more fuel- resp. CO_2-efficient technologies belong to this second category, implying slower restructuring cycles. Generally, the implementation processes are technically “determined”, but can be politically accelerated or delayed. The potential for this type of continued additional GHG reduction is very significant but it will take in the order of 10 years or more, i.e. with a time horizon of around 2020: The governing processes are technological development to market maturity and the turnover cycles of the vehicle fleets.

The introduction of new engine technologies to further reduce the per KM emission for new cars is a typical and significant example: The process has a penetration cycle of around 10 years,

---

[76] assumed for 2012 in chapter 5.1

and this only after the technology has been developed to market maturity. However, the additional reduction potential for the transport sector is significant in the order of some 50 Mtonnes/a for M1 vehicles in the EU15 alone[77], see Figure 37.

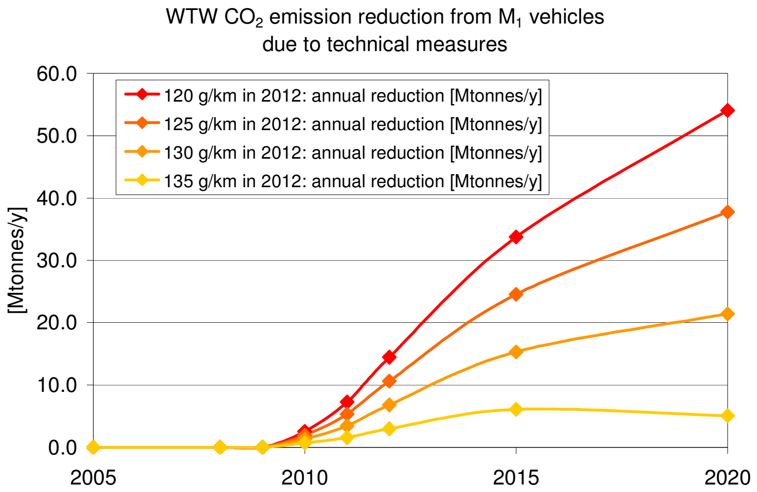


Figure 37 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO2-eq. p.a.) for EU15 resulting from technical measures applied to passenger cars in order to reach a 2012 target between 135 and 120 g/km (See chapter 5.1).

Similar processes have been identified in chapter 5.2 for the HDV sector, also showing development plus market penetration cycles of more than a decade. This means that long term (technical) reduction potentials are significantly higher than those up to 2012[78].

GHG reduction in other sectors

If the economy as a whole is considered, interactions between the transport and other sectors become relevant. Then the emission volumes, the relative MACs, and the dynamics of further GHG reductions beyond 2012 in the other sectors must be compared with similar PAM characteristics in the transport sector.

On the basis of our analyses the building and the power supply sectors (chapter 4) are interesting examples from the point of view of economically attractive PAMs for further GHG reductions. More efficient heating and insulation systems in new buildings (or retrofitting the existing

---

[77] As we are talking here about a time horizon of 2020 and even beyond, the additional reduction potential in the 10 new member states could be another significant long term contribution.

[78] In chapter 5.2, for engine improvements a reduction of 0.7 Mtonnes/a is estimated by 2012, but some 22.6 Mtonnes/a by 2020.

stock), will show long life time cycles of 20- 30 or even more years. The replacement of power plants with more efficient technologies is a similar example, the most significant contribution coming from replacing old coal fired plants with the NGCC technology.

Overall assessment

Looking at the longer term GHG reduction potentials – beyond 2012 – of the different policies and measures one finds that:

1. Rapid further reductions in the transport sector have a limited potential, because those PAMs are assumed to be implemented largely by 2012. Intensified efforts to accelerate the implementation of ecodriving in the PC and HDV subsectors could yield the best potentials, depending on political priorities actually implemented.
2. However, significant further reduction potentials exist in the longer run, both in the transport sector and other sectors, notably energy supply, industry and the building sectors.
3. Further GHG reductions even in the long run generally show lower MACs for important PAMs in the building and the energy supply sector compared to actions in the transport sector. From the standpoint of the overall (static) economy, this might suggest to focus on the intensification of PAMs in the non-transport sectors, largely exempting the transport sector from further GHG reductions; the argument being to first implement the PAMs with the lowest MACs.
4. However, assuming a longer term (and dynamic) view of the economy, including aspects of long term competition of the European car industry at the global scale, the conclusion might be quite different: on the background that – for example – Japanese and other Asian Car industries are making faster progress in fuel and GHG-efficient vehicles, it could be a risky policy to only consider the static cost situation of the present. Since future trends in the world markets are clearly directed toward high-efficiency transport technologies, then the conclusion for the European Car industry could be to focus heavily on coming back to the technological forefront of CO_2-efficient vehicle technologies, pursuing the implementation processes identified in chapters 5.1. and 5.2.

8. THE EXTENSION OF ETS

8.1. BACKGROUND

The preceding chapters have demonstrated the possibilities and costs for a reduction of greenhouse gas emissions. As an instrument to achieve this reduction, the Kyoto protocol allows for the use of so called flexible mechanisms. One of these mechanisms is “Emissions Trading”, often also referred to as “cap and trade”. Emissions trading is commonly assumed to realise emission reductions at lower costs than regulative approaches because of the flexibility of reduction measures. The following chapters outline the theoretical approaches to how emissions trading could be applied to the road transport sector and assess what some of the effects of emissions trading might be. In a first step, the general principles of emissions trading and framework conditions are described. Afterwards different designs and approaches for emissions trading in the transport sector are broadly discussed together with a more focused look at the potential effects of extending the EU Emissions Tranding Sceme to car manufacturers. Finally, an overview of the next analytical steps which would be required in assessing the feasibility of using emissions trading in road transport is given.

How emissions trading works

Emissions trading basically functions as follows: Based on the targets e.g. of the Kyoto protocol, a central authority sets a limit (cap) of a defined amount of allowed emissions for a certain group of emitters, which is represented by emission certificates. All emitters have to hold certificates which correspond to their emissions.

Participants have the possibility to get certificates at the beginning of a trading period. The certificates can be distributed e.g. by auction or free of charge according to an allocation plan. Participants who have higher emissions within the trading period than they hold emission rights for have to buy certificates, actors which emit less than their allowance can sell certificates. The process of buying and selling emission certificates is the actual “emissions trading”. It is assumed that emitters which have high costs for reducing emissions will buy certificates, emitters with low costs can earn money by reducing emissions and selling certificates. The price of emission certificates in theory evolves on the free market following supply and demand. In a functioning market and ideal conditions, this will lead to a situation where the necessary emission reductions are undertaken where they lead to the lowest costs (Coase Theorem). Therefore it is assumed that emissions trading will achieve emission reductions in a cost-efficient way.

Current emissions trading in the EU

In 2005, an emissions trading scheme (ETS) has been introduced by the European Union which covers stationary combustion installations with a thermal capacity of over 20 MW and other industrial installations, such as refineries and steel production ([EC 2003]). The first trading phase is from 2005 to 2007; the second corresponds to the first commitment period of the Kyoto protocol and will thus be from 2008 to 2012. Today some 12.000 installations are covered by emissions trading, representing almost half of the EU CO_2 emissions[79].

The EU emissions trading Directive ([EC 2003]) already expressly mentions an extension of the scheme to other sector and greenhouse gases: "*From 2008, Member States may apply emission allowance trading in accordance with this Directive to activities, installations and greenhouse gases which are not listed in Annex I …*".

From the transport sector, however, only pre-chain emissions (see Figure 38) such as emissions from the production of fuels in refineries or electricity for transport in power plants are included in the current ETS-System. Only for railway transport, which mainly uses electricity, the major part of the emissions is thus covered. Exhaust emissions from transport and also households are not yet included (see Figure 38). In road, water and air transport, these emissions mainly come from the use of fossil fuels (Diesel, Gasoline and Kerosene) which are used in combustion engines or turbines.

---

[79] http://www.europa.eu.int/rapid/pressReleasesAction.do?reference=MEMO/04/44&format=HTML&aged=1&language=EN&guiLanguage=en#fn1

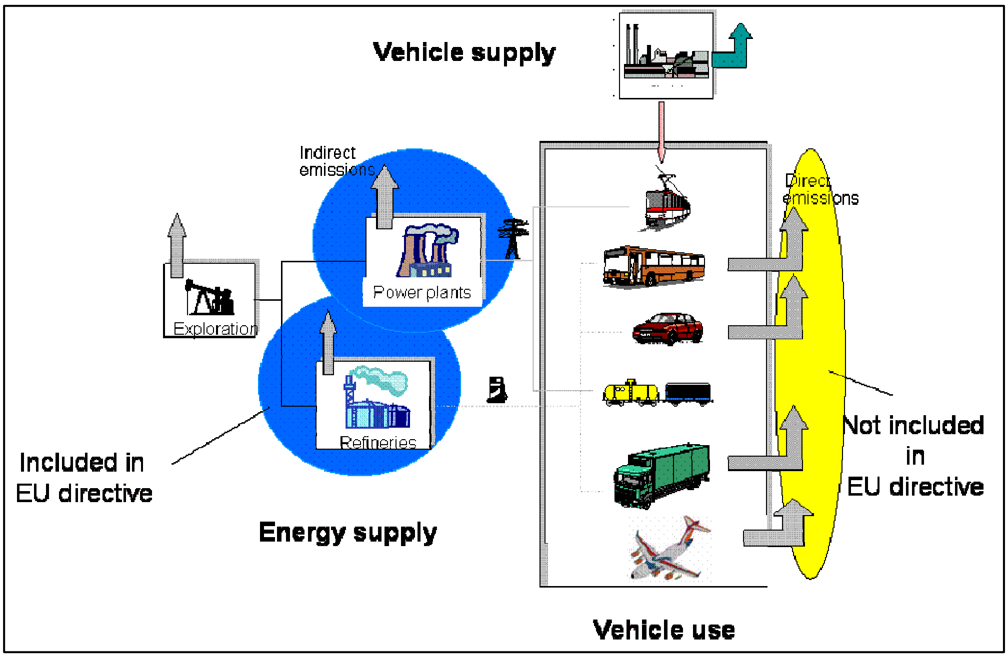


Figure 38 Transport related CO_2 emissions (schematic presentation)

Inclusion of transport in EU emissions trading

Despite the voluntary commitment of the automotive industry to reduce the specific emissions from new cars, carbon dioxide emissions from transport have continuously increased and are projected to further increase [EEA 2005]. This is because reductions in specific emissions have been overcompensated by the increase in traffic volume, especially in goods traffic and aviation.

The introduction of emissions trading in the transport sector is one option to achieve the targets of the Kyoto protocol by stimulating a cost effective reduction. Several possible designs and potential points of liability which allow for an inclusion of the transport sector in European emissions trading are subsequently described and discussed. Since the inclusion of air transport in the existing ETS is already considered and discussed by the Commission[80], the focus here is mainly on road transport which is responsible for the major share of transport related carbon dioxide emissions.

Descriptions and assessments are based on previous studies by IFEU or with IFEU participation ([IFEU 2001], [IFEU 2003], [FiFo et al. 2005]) as well as other leading studies on emissions trading in the transport sector such as [CCAP 2000], [PwC 2002], [CE 20005] and [IPPR 2006a]. Besides a qualitative description of different systems, also an illustrative quantification

---

[80] http://ec.europa.eu/environment/climat/aviation_en.htm

of different designs is undertaken. New analysis is included in the section evaluating some of the possible effects of opening the EU ETS to car manufacturers.

8.2. DESIGNS OF AN EMISSION TRADING SCHEME FOR THE TRANSPORT SECTOR

Emissions trading requires a "smart design" in order to lead to economic and ecological optimal effects. In this chapter, first the most relevant factors for the design of an ETS system and their impact on the efficiency of the trading system will be described. Afterwards different approaches of an ETS System for the transport sector will be discussed and compared against this background. The most important parameters to consider are:

- Target setting (absolute and specific targets)
- Allocation procedures
- Open and closed systems

These parameters are discussed in the following chapters. Afterwards an indicative discussion of the possible effects on reduction costs and other sectors is undertaken based on the MAC curves.

8.2.1. TARGET SETTING

A prerequisite for an emissions trading scheme is the definition of an emission target which is to be achieved and which can be monitored. Emission targets can either be defined as an absolute value for each participant or as a specific value in relation to a certain performance (in transport e.g. tonne-km, passenger-km, vehicle-km). Accordingly, emission reduction targets can also be defined in these two ways.

Absolute targets are suitable to achieve the compliance with a defined total reduction of emissions (e.g. tonnes of carbon dioxide). Such systems are usually called "cap-and-trade" systems. The sum of all allowances of the actors in a sector corresponds to the politically set allowance of the sector. An absolute target will therefore be appropriate to ensure the compliance with the target of the Kyoto protocol which also specifies an absolute target for the European Union. It ensures that the target is met even in times of economic growth in which increasing production or transport volumes may occur. On the other hand, absolute emission targets can be perceived as growth barriers for a sector, because for a shortfall of certificates will prevent the increase of production or transport volumes.

Specific targets are defined for a certain activity (e.g. g CO_2/ vehicle-km) or product (e.g. kg CO_2/ vehicle) and require a so called "baseline-and-credit" system. Such system does not allocate absolute emission rights, but defines a reference scenario – the baseline. For differences to the baseline, reductions certificates are either issued in case of lower specific emissions compared to the target or have to be bought in case of higher specific emissions compared to the target.

Such specific targets, however, can not guarantee the achievement of a certain absolute target e. g. as specified by the Kyoto protocol. Since specific targets have to be multiplied with production volumes or transport activity this approach will risk that a reduction in specific emissions is overcompensated by an increase in transport activity. In this case the total amount of emissions may increase, despite a reduction in specific emissions, because additional emission certificates are generated due to the lack of an absolute cap.

A difficulty of a specific target is thus the direct incompatibility with the absolute targets currently defined in the EU emissions trading for stationary sources. In order to reduce the risk of missing the target, a gateway between the transport sector and other markets can be introduced. This would allow for unrestricted buying from the transport sector, but ensures that certificates from a sector with a specific target can only be sold to a sector with an absolute target if certain requirements are met [IFEU 2003].

A gateway system has already been implemented in the UK emissions trading scheme which is based on voluntary participation: “For firms with 'relative' (efficiency-based) targets … to buy and sell allowances with firms that have 'absolute' emissions reduction targets, they have to transfer allowances through a gateway. The gateway does not affect trading between firms with relative targets. Nor does it prevent trading with firms that have absolute targets. However, one allowance must be transferred from the absolute to the relative sector before one allowance can be transferred in the other direction. Put simply, this is a one-out, one-in system”[81]. Otherwise the absolute amount of certificates could eventually increase also in the sector with an absolute target.

8.2.2. ALLOCATION PROCEDURES

In order to implement emissions trading, the total budget of carbon dioxide emissions for a trading period as defined by the target for a sector has to be specified. All actors in the sector have to hold certificates according to their amount of emissions within a trading period. Several methods for an allocation of certificates to the actors exist (see [IFEU 2001], [IFEU 2003], [FiFo et al. 2005], [CCAP 2000], [PwC 2002], [CE 2005] and [IPPR 2006a]).

---

[81] http://www.defra.gov.uk/environment/climatechange/trading/uk/archive.htm

In case of **free allocation** (grandfathering) certificates are allocated based on criteria such as recent market share or previous emissions (called grandfathering) of a certain company or sector. The distribution of certificates is defined in an allocation plan[82]. Generally, early base periods for the allocation of certificates will more adequately consider advance reductions of the participants (early action). Early base years, on the other hand, are often problematic, due to availability of data or the fact that some companies might have been established only after the base year. The procedure of allocating certificates to different entities is complex and might involve substantial costs. Allocation procedures are not always transparent and this intransparency might have negative impacts on the market (e.g. price crash after the publication of verified emissions data for 2005). In case of free allocation to incumbents it is common that a certain amount of certificates is placed in a New Entrant Reserve so that it can be issued for newcomers in the market.

Free allocation enjoys a high acceptance among the industry because no up-front costs occur and also planning reliability is higher. A disadvantage of free allocation is that the process, since it encourages rent-seeking, might be influenced by many individual interests (lobbying) and could lead to counterproductive effects considering ecological efficiency[83]. Furthermore, the current EU emissions trading has shown the risk, that the liable actors pass on to the end consumer the opportunity costs for certificates, which they have received free of charge ("windfall profits").

Benchmarking is another possibility of free allocation. It considers either average emissions involved in the production of a homogeneous good in the past or the current available technology (BAT). Potential values for benchmarking could be e.g. the carbon dioxide emissions for a certain performance (transport performance, product, etc.). Benchmarks thus could give a special advantage to environmental friendly practice in rewarding early action.

Since all approaches for free allocation will not be able to allocate certificates according to the respective emissions of every installation, trading will be necessary. Thus participating companies can thus either sell not required or have to buy additional certificates.

Auctioning means that certificates are sold to the participants. The emission certificates are auctioned in regular intervals for the defined trading period. Every participant can purchase by auction the amount of certificates which is estimated to be needed for own emissions or wanted for trading. The price for certificates is thus already established in the beginning of the trading

---

[82] e.g. http://ec.europa.eu/environment/climat/emission_plans.htm

[83] e.g. if allocation leads to unequal treatment of different energy carriers (e.g. coal and gas)

period. If too many or not enough certificates have been bought by an actor, these certificates can be either sold or additional certificates have to be bought on the market.

Auctioning allows for a suitable integration of new actors, because they are able to buy the certificates at the same conditions as their competitors. The revenues from the initial auction can be used by the respective governments e.g. for further emission reductions, for the reduction of taxes or recycled back to the covered sectors of the trading scheme. Despite this benefit for the national economy, this approach is assumed to be less popular among the potential actors, due to the direct costs for emission rights and financial risks. Also for this procedure, a liquid and transparent market is necessary. In case of shortness of certificates, there is the risk of strategic holding of certificates to harm competitors if only few actors and especially competitors are in the market. Even if the entire revenues of the auction are used for tax reductions, a redistribution of revenues will take place and can also lead to distortions.

Auctioning, however, follows most closely the "polluter-pays-principle" and is thus regarded to be more equitable from an environmental economic side. Furthermore, the transaction costs of grandfathering are assumed to be higher as for auctioning. Therefore an auction system appears to be more suitable for public administration.

Combinations between both designs (grandfathering and auctioning) according to defined shares can be referred to as **hybrid systems**. The allocation for the first period of emissions trading for stationary sources from 2005 was mainly based on grandfathering, though auctioning of up to 5% of the certificates was at the discretion of the Member States. Auctioning is now considered by more countries for the second period starting from 2008 in which up to 10% of the certificates can be auctioned ([IPPR 2006a]).

8.2.3. OPEN AND CLOSED TRADING SCHEMES

Principally, certificates can be traded within a sector or state (closed) or between sectors and/or states (open). Both designs have different effects on the ecological and economic efficiency of emissions trading.

In a **closed system**, trading would only be undertaken between actors in the considered sector (e.g. transport) and within a defined political territory (e.g. the European Union). Trading with other sectors and regions is not permitted; reductions thus have to be achieved within the sector and entity. From a least-cost perspective, several disadvantages are associated with a closed trading scheme: Only the reduction options within the sector can be made use of, while the options in other sectors are not available. This limited number of reduction options potentially leads to higher reduction costs – especially if the affected sector has high reduction costs which have not been taking into account when splitting the target. Furthermore, there could be a smaller number of actors and thus a higher risk of market power.

An **open system** on the other hand could allow for a trading of certificates between sectors and between different countries. Such an open system is assumed to be more cost efficient and thus comply better with the idea of the Kyoto protocol. The Kyoto protocol envisaged an open trading system which allows for trading between ratifying countries and also between sectors which are part of the emissions trading system within one country. From a theoretical economic standpoint, such an open system leads to lower reduction costs to meet the same target compared to a closed system.

Because of its low price elasticity on the demand side and the high reduction costs, the transport sector could mainly act as a buyer of certificates from other sectors in an open system. This could also lead to distortions in the other sectors and create a risk of reducing the stimulus to innovate (if car manufactuers would be the liable actors). This issue is addressed further in Section 8.3., which deals specifically

The economic efficiency of an ETS theoretically increases with the difference in marginal abatement costs of the liable actors. Considering this, the current EU ETS and also the Kyoto protocol, an open system appears to be more feasible and will probably lead to lower costs. The design of such a system, however, will also depend on further political targets. If emissions are to be reduced within the transport sector, a closed system is more appropriate; if emissions are to be reduced at the lowest costs, an open system is advised.

8.2.4. APPROACHES TO EMISSIONS TRADING FOR TRANSPORT

Generally, according to the “polluter-pays-principle”, every actor who is responsible for emissions can be made liable to hold the respective certificates. However, there will be differences in ecological and economic efficiency, depending on the chosen regulation access.

- Under **target aspects**, emissions trading will be most effective if all emitters and thus all emissions are covered by the trading scheme. This guarantees that the overall reduction target is achieved.
- Under **economic aspects**, it is often assumed that an ETS which covers all emissions and therefore reduction possibilities will lead to lowest reduction costs. Furthermore it will be desirable to reduce the costs for implementation and administration (“transaction costs”). Therefore e.g. the number and size of liable actors should be considered.

- Finally, an ETS is often considered to be more effective if the liable actors have **direct possibilities for emission reductions**.

The following theoretical approaches to implement emissions trading in the transport sector are discussed in this section under these aspects:

- In the transport sector, a downstream approach (at the end of the fuel supply chain) could make all the **operators of transport vehicles** liable to hold certificates for the emissions of their vehicles. Operators of transport vehicles can directly influence their emissions by making the actual travel decisions and also by their preference for vehicles and also the maintenance of vehicles. However, there is a large number of small mobile sources (e.g. every private motorist).
- Also the **producers of transport vehicles** could be made liable actors of emissions trading. In this case, vehicle manufacturers are required to hold certificates for the (estimated) emissions of the sold vehicles. Vehicle manufacturers have many technological possibilities to influence the fuel efficiency and thus emissions of the vehicles. The manufacturers also have an influence on the purchase decision of customers by their marketing strategy. The influence on actual vehicle miles travelled, total fuel consumption and CO_2 emissions, however, is limited. The precise ex-ante estimation of the amount of emissions of a vehicle is thus difficult.
- At the beginning of the fuel chain, the **suppliers of transport fuels** can be a point of liability to be considered. Fuel suppliers (refineries, fuel trading companies or importers) can be made liable for the emissions because of the direct relation between the carbon content of fuels and CO_2 emissions. Such an “upstream-approach”, makes the producers or importers of fuels for transportation liable to hold certificates. Only limited options for emission reductions are available directly. However, through the pass-through of costs the incentive to reduce emissions will be transferred to the operators of transport vehicles.

The main reduction options for three different approaches are described in more detail in the following chapters. As a first evaluation, also the main chances and risks of the different approaches are discussed. In addition further and more detailed consideration is given to the possibility of opening the EU ETS to producers of transport vehicles (car manufacturers).

8.2.5. OPERATOR OF TRANSPORT VEHICLES AS LIABLE ACTORS (DOWNSTREAM APPROACH)

Liable actors and coverage

In limiting the direct CO_2 emissions of the transport sector at the level of the end consumer of fuels, the “polluter-pays-principle” is most adequately implemented. The type of potential actors is very different, ranging from individual motorists to larger companies. Also passenger and goods transport have to be distinguished. Especially considering passenger cars, the number of actors is very high.

In practice, the downstream approach would require every motorist to either document his fuel consumption and the corresponding emissions certificates e.g. at the end of each fiscal year or to transfer the respective amount of certificates with every fuelling. This may be perceived by many as a limitation of individual freedom in the sense that “fuel coupons” are needed to maintain mobility. “In principle, information technology (IT) is up to the task of enabling administration of a scheme but the risks and costs of implementing major IT projects are large” ([IPPR 2006a]). Many studies therefore come to the conclusion that a downstream approach is today not feasible for the entire transport sector (see [IPPR 2006a], [PwC 2002], [IFEU 2003], [FiFo et al. 2005]).

A downstream trading for certain sub-sectors such as aviation or goods traffic, however, would be more feasible (see [PwC 2002], [IPPR 2006a], [CE 2005]), but only partly covers the transport emissions and might lead to the unwanted effects described earlier. It may also be difficult to justify such limited emissions trading, if no similar scheme is implemented for the rest of the transport sector. Especially as part of open trading systems, however, downstream trading for different sub-systems can be suitable. In aviation, for instance, there are only about 774 aircraft operators in the European Union ([CE 2005]). For goods transport, in which an increase in emissions is expected over the next years, previous IFEU studies ([IFEU 2001], [IFEU 2003]) discuss the freight forwarder as a possible regulation access. This leads to a lower number of actors compared to the passenger car sector and therefore more adequate transaction costs.

Reduction options

In general, the operators of transport vehicles have many options to influence the emissions such as route decisions, vehicle choice, vehicle maintenance, driving behaviour etc. This also applies to freight forwarders which can optimise their load factor and route concepts, purchase efficient vehicles or promote efficient driving. Since fuel consumption is already regarded to be a cost factor in goods transport, some optimisations have already been undertaken.

Target definition and effects

An absolute cap could be defined for each operator in case of grandfathering ("allocation plan"). This is associated with the above mentioned problems of establishing an allocation plan. In other cases every operator has to buy certificates from the market which correspond to their emissions.

Also a specific target could be defined for the transport performance in tonne-kilometre for different vehicle types. The specific target can also be based on an absolute reduction aim for the sector and the estimated transport performance for the trading period. The assessment of specific emissions for certain goods will be difficult for mixed cargo and in combined transport.

With the specific target an absolute emission reduction can not be ensured. If the transport volumes have been underestimated or are growing, the absolute emissions may actually be increasing despite an improvement in specific emissions. In case of open trading with other sectors which have absolute targets, a gateway system would be necessary.

Exemplification of the cost impact for freight forwarders

For exemplification, a specific target of 100 g of CO_2 **per tonne-km** and a certificate price of 20€ per tonne of CO_2 is assumed.

- If road transport (e.g. for light goods) has specific emissions of about 180 g of CO_2 per tonne-km - thus 80 g CO_2/tkm higher specific emissions than the target - this would lead to costs of about 0.16 cent/tkm. If 10 tons are transported 100.000 km for a freight forwarder 180 t CO_2 are emitted. This is 80 t CO2 more compared to a specific emission rate of 100 g/tkm – therefore additional costs of 1.600 € arise for the freight forwarder.
- If the same goods are carried by rail with specific emissions of 90 g CO2/tkm - thus 10 g CO_2/tkm lower specific emissions than the target – this would lead to a cost relief of 0.02 ct/t-km. The total emissions for 10 tons of goods transported 100.000 km would be 90 t CO_2, this is 10 tons less compared to a transport which meets the specific target of 100 g CO_2/tkm. The cost relief for the freight forwarder would be 200 €.
- In this example, transport by rail leads to 1.800 € lower costs compared to transport by road.

Chances and risks

- Downstream trading for the entire transport sector would have the disadvantage of a very high number of actors and thus high transaction costs. The number of actors in certain sub-sectors (e.g. goods transport, aviation) would be much lower, but also limits the amount of covered emissions.

- Downstream trading allows for a wide range of reduction options on the side of the liable actors.
- A specific target can not ensure that absolute reduction targets or caps are achieved.
- The assessment of specific emissions for a baseline and credit-system is difficult for mixed cargo and in combined transport. Also the treatment of different goods with different specific weights (e.g. coal vs. electronics).

Overall, the downstream approach is not suitable for the entire transport sector, but could be considered for certain sub-sectors. There are several disadvantages associated with specific targets, e.g. that an absolute emission reduction can not be ensured if transport volumes increases more than expected. The main advantage is the possibility for direct reductions on the side of the liable actors (choice of vehicles, loading and logistics, driving behaviour, etc.).

8.2.6. PRODUCER OF TRANSPORT VEHICLES AS LIABLE ACTOR

Liable actors and coverage

The producers of transport vehicles could be made liable to hold certificates for the emissions of the vehicles they sell. This would mean that in the beginning of the ETS only emissions of new vehicles are covered by this approach.

Generally a wide range of vehicles is used of which passenger cars and trucks have the highest contribution to transport emissions. Beside vehicle size and weight, also the intensity of use is very different, ranging from limited use of private passenger cars to continuous long-term use of commercial transport vehicles.

Due to the uncertainties in the assessment of total life-time emissions and due to the fact that the emissions of trucks, trains and aircraft often also occur outside of the European Union, emissions trading at the manufacturers level seems to be suitable mainly for passenger cars which will thus be described in this chapter.

Reduction options

Vehicle manufacturers can directly reduce the specific emissions of their vehicles with changes in vehicle aerodynamics and weight, engine efficiency, etc. Furthermore, they can influence the demand for efficient vehicles through their marketing strategy. A reduction of specific emissions has an effect over the entire life-time of the vehicle.

Target definition

The individual use of vehicles (vehicle miles travelled, driving behaviour), can not be influenced directly by car manufacturers. Furthermore, emissions occur over a longer period – the whole operational life-time of the vehicle – and at different places. The exact amount of emissions in a certain reference year by the vehicles of a certain manufacturer can therefore not be determined without resorting to estimations. These would have to be estimated (crudely) by assuming a certain lifetime or total mileage and specific CO_2 emissions. The exemplification below shows the impact of a specific target (120 g CO_2/km) on the costs for the producers. Section 8.3. buids further on this approximation so as to provide a rough estimate of the potential impacts of including car manufactueres in an open emissions trading scheme.

On the other hand, vehicle manufacturers have direct influence on the efficiency of vehicles. Furthermore, it is a strategic goal of the EU to reduce the specific emissions of passenger cars e.g. to 140, 130 and later to 120 g CO_2/km. The declared aim of such an approach is to increase the efficiency in a specific sector (passenger car in this case). Hence, within the timeframe applicable to current EU targets (e.g. 2012) an approach with the vehicle producers as liable actors is likely to imply that the focus is on specific rather than absolute emissions, i.e. on g/km rather than tonnes. To guarantee the achievement of the specific goal (g CO_2/km), trading between the manufactures seems most appropriate. This section briefly looks at the “closed approach” to emissions trading while Section 8.3. addresses the possible impacts (particularly in terms of costs) of using an open emissions trading system for car manufacturers.

It has to be mentioned that there is a basic difference between this approach of “standard trading” (in g/km) and the framework of emission trading where a reduction of the emissions are to be achieved at minimal costs (across all sectors). Nevertheless, trading still can play a role in such an approach: It can be used for implementing this regulation in an economically efficient way. In a trading system, the differences of the specific emissions of a passenger car (in g CO_2/km) to a target (baseline) could be traded. The manufacturer would then have to buy certificates for each passenger car he sells with higher specific emissions than this target or can compensate these higher specific emissions internally. If the specific emissions of a passenger car remain below the target, certificates can be sold or used to compensate for vehicles with higher specific emissions internally. How the strategic goal of attaining a certain CO_2-efficiency level (in g/km) is realised is not a priori clear. Fixing a certain value for each manufacturer is one possibility – though economically not necessarily efficient. As an alternative, one could consider different reduction targets related to parameters such as the footprint or weight of the vehicle to take into account the diversity of products of the EU passenger cars market. Such a set of reduction targets, however, can not ensure the achievement of a certain overall target. In whatever way the targets are defined, the system should be designed in such a way that trading will take place, i.e. the liable actors do have an incentive for trading. This requires that there will be sellers (and not only buyers) of certificates, i.e. manufacturers who know and implement their technical (and economically feasible) strategies to reduce specific emissions below the target. A possible approach could be a continuous yearly decrease of the target starting from todays emission levels. A trading system then offers the possibility for cost minimisation to achieve the targets.

The described system is not a classical ETS since not absolute tons of emissions of CO_2, but only specific standards (g CO_2/km) are traded. A number of open issues for implementation need to be looked at in more detail and could not be discussed further in this study. For example a connection to the current ETS[84] would be complex and involve considerable uncertainties (gateway for the intersectoral exchange with the need for rough estimates of emissions for a reference year, how sanctions in case of non-compliance are defined etc.). The different possibilities about the cash-flow have to be investigated (between companies, between countries, establishing and supporting an efficiency fond….). It also has to be studied what will be the price of standard trading in a closed system (oriented at reduction costs of producer – higher than in the below mentioned example).

Exemplification of the cost impact for vehicle manufacturers

For exemplification, a specific target of 120 g of CO_2 per km and a certificate price of **20 €** per tonne of CO_2 is assumed. If the full amount of certificates for the difference to the target has to be bought, this would have the following effects:

- A large gasoline vehicle has an emission rate about 240 g CO_2/km (fuel consumption of about 10 l per 100km) and a life-time mileage of 200.000 km; the difference to 120 g CO_2/km (120 g/km) results in 24 t CO_2 higher life-time emissions compared with a car with 120 g CO_2/km and leads to additional costs for buying certificates of about 480 €.
- A small gasoline vehicle has an emission rate about 100 g CO_2/km (fuel consumption of about 3.7 l per 100km) and a life-time mileage of 200.000km; the difference to 120 g/km (- 20 g/km) results in about 40 t CO_2 lower emissions and leads to cost relief of about 80 €.

In the case of lower certificate prices or (partial) free allocation, the effect could be lower.

---

[84] Where tonnes, not standards are traded

Chances and risks

The manufacturer approach has a range of advantages:

- The system provides direct incentives for the manufacturers for applying innovative, high efficiency technology to reduce the emissions of their models since there are many technical options on the side of the manufacturers to reduce specific emissions. A trading system on this level can stimulate innovation.
- There is only a limited number of passenger car manufacturers, transaction costs can therefore be estimated to be much lower than for approaches with large numbers of liable actors.
- For specific emissions of passenger cars the New European Driving Cycle (NEDC) is already established and gives a good indication of the average fuel consumption. Furthermore, the basis for a potential monitoring system has already been established .

Beside these advantages, a range of considerable risks has to be considered:

- It has to be ensured that trading is actually taking place in such a limited market with few, directly competing actors. This might require complex governmental control in order to give the actors planning reliability. At the same time an effective system of early detection and control of possible non-compliance, as well as a credible related sanction system is a crucial precondition to ensure trading.
- Since the system is focused on a specific sector only (passenger car) it is economically less efficient than a system open to all sectors.
- Due to the specific target, the achievement of absolute emission reductions in tonnes can not be ensured since the overall emissions also depend on the number and length of trips, the individual driving behaviour etc.
- Linking to the current ETS would be complex and involve considerable uncertainties (for a more detailed discussion of including car manufacturers into the open ETS, see Section 8.3.)
- If linked with the current ETS: Probably a flow of certificates from the stationary ETS-market (car producers as buyer) because of the higher marginal abatement costs in the transport sector and therefore no guarantee to archieve the specific goals for the transport sector.

8.2.7. SUPPLIER OF TRANSPORT FUELS AS LIABLE ACTOR (UPSTREAM APPROACH)

Liable actors and coverage

The regulatory access for this approach is the beginning of the energy chain; the approach is therefore referred to as an "upstream approach". The suppliers of transport fuels (refineries, fuel trading companies or importers will be liable to hold certificates according to the fossil carbon content of the sold fuel. Since mobility generally requires energy, all carbon dioxide emission from transport can be covered by such an upstream approach. In the transport sector, gasoline and diesel fuel as well as kerosene have the highest contribution to the total emissions. Furthermore, also natural gas is used in many countries and should be considered, while biofuels "… should be exempted, since their carbon content is renewable" ([IPPR 2006a]). If other types of fuels such as heating oil are covered, also energy related emissions of other sectors such as households could be principally included with this approach.

The wide coverage of emissions and small number of participants, and thus the low transaction costs, have been identified as one main advantage of this approach ([PwC 2002], [IPPR 2006a], [IFEU 2003], [FiFo et al. 2005]). Furthermore, existing structures for taxation can be used. The liable actors will pass-through the costs for the certificates in their prices. Price elasticity and market structure determines whether the costs for certificates can be fully passed on to the end consumer or only partially. In addition to the certificates, also transaction costs arise for the fuel suppliers.

Reduction options

The liable actors themselves have only limited possibilities to achieve emission reductions. A possible option would be the introduction of biofuels. However, the choice for a certain means of transport, the efficiency of engines or the transport volumes can not be directly influenced. The additional costs for the certificates are passed on from the fuel traders to the actual emitters. For the end consumer, the effect of upstream trading is similar to an additional tax on CO_2 emissions. If the market is not perfectly functioning, the costs (opportunity or real costs) may also only partly be passed on to the emitters, which then do not have an adequate incentive to reduce their emissions.

Target definition

An absolute cap can be defined in this upstream approach which ensures the achievement of an absolute reduction target. Since the liable suppliers of transport fuels do not have technical possibilities for reducing their emissions, trading with certificates in a closed transport trading system is mainly a transfer of market shares of transport fuel. In an open system also certificates from other sectors can be bought - if this is cheaper - and the additional costs can be included in the fuel price.

The overall impact will be an increase in fuel prices. The increased fuel costs may lead to an increasing demand for more efficient vehicles or to a change in the modal split due to the differences in costs depending on the carbon content ([PwC 2002]). Diesel fuel, for instance, will get more expensive compared to gasoline due to the higher carbon content. It can be questioned however, if a small price increase (see example below) will have a noticeable effect on transport volumes, modal split and vehicle demand ([FiFo et al. 2005]). A sharp increase in prices can only be expected in a closed trading scheme for the transport sector, while in an open system, the increase in the price will be lower, since cheaper abatement options are available in the other sectors.

Exemplification of price differences for fuel

For exemplification, a certificate price of 20€ per tonne of CO_2 is assumed. If the full amount of certificates has to be bought, this leads to a price increase of about 5.2 cents per litre of diesel fuel and 4.8 cents per litre of gasoline fuel. In the case of (partial) free allocation, the price increase can be lower.

Chances and risks

› The complete coverage of transport emissions with a limited number of actors is regarded to be the main advantage of this approach.
› The liable actors will not have many reduction possibilities themselves. They will try to pass on the price for certificates to the end consumer, which then has an incentive to reduce his emissions.
› An absolute cap can be defined which ensures the achievement of absolute emission reductions.

8.2.8. COMBINATION OF APPROACHES

A combination of the discussed approaches could also be considered. Thereby the idea is not to combine two different approaches into one single trading system, but rather to apply two approaches working separately but in parallel. Though emissions trading is still difficult to implement at the end-consumer level (downstream), this may become more feasible in the future along with further improvements in information technology. Generally, the following combinations are discussed as interim solutions:

- Combination of upstream (fuel supply) and downstream (freight forwarder) approach
- Combination of upstream (fuel supply) and car manufacturer approach
- Combination of car manufacturer and freight forwarder approach

One main advantage of the upstream approach is the possibility to cover the entire transport emissions. With a combination of the upstream approach with any of the other approaches, it has to be ensured that there is no double counting. Actors covered by one of the other approaches may have to be exempted to hold certificates for the upstream system.

The **combination of upstream (fuel supply) and downstream (freight forwarder) approach** requires that the liable freight forwarder does not have to hold and surrender certificates for their fuel. If the freight forwarder is able to document his CO_2 emissions from fuel consumption, the certificate price could be rebated at market price. The participating freight forwarders would thus effectively not need extra certificates for their fuel. This system, however, will lead to considerable additional transaction costs without an additional benefit regarding emission reduction and is thus not favourable.

A **combination of upstream** (fuel supply) **and car manufacturer approach** (trading standards in g CO_2/km) is compatible since the two underlying goals complement each other: the upstream approach is targetted towards the direct reduction of absolute emissions while the car manufacturer approach is primarily an accompanying instrument to implement the strategic goal of increasing CO_2-efficiency of vehicles and hence reducing related emissions indirectly. In the end this will lead to a lower number of certificates being required in the transport sector as part of the upstream approach. This combination of both approaches would be beneficial already in the short run in order to close the time lag, and give vehicle manufacturers right from the beginning an incentive to develop and market less carbon-intensive and more fuel-efficient vehicles. In parallel the fuel supply companies could be given an overall cap of emission certificates, leading to an increase of fuel prices.

The **combination of vehicle manufacturer and freight forwarder approach** is in principle compatible since both approaches cover different segments of road transport. Therefore double counting does not occur. The combination would also overcome the disadvantage of the two approaches, that they cover only single segments of road transport. However, the basic approaches differ since the freight forwarder approach is targetted towards absolute emissions while the car manufacturer approach is an instrument to achieve the EU efficiency targets and reduces emissions only indirectly. In addition, both approaches leave some open questions (e.g.

the feasibility of the freight forwarder with its complex market structure and the impacts of different allocation procedures, implementation issues of the car manufacturer approach).

8.3. FOCUS ON OPENING THE ETS TO CAR MANUFACTURERS

At the request of the Commission, this section provides additional analysis regarding the feasibility of opening the present EU ETS to the transport sector with car manufacturers as liable actors. In order to do this, the example provided in Section 8.2.6. above has been elaborated on further:

Exemplification of the cost impact for vehicle manufacturers

For exemplification, a specific target of 120 g of CO_2 per km and a certificate price of **20 €** per tonne of CO_2 is assumed. If the full amount of certificates for the difference to the target has to be bought, this would have the following effects:

- A large gasoline vehicle has an emission rate about 240 g CO_2/km (fuel consumption of about 10 l per 100km) and a life-time mileage of 200.000 km; the difference to 120 g CO_2/km (120 g/km) results in 24 t CO_2 higher life-time emissions compared with a car with 120 g CO_2/km and leads to additional costs for buying certificates of about 480 €.
- A small gasoline vehicle has an emission rate about 100 g CO_2/km (fuel consumption of about 3.7 l per 100km) and a life-time mileage of 200.000km; the difference to 120 g/km (- 20 g/km) results in about 4 t CO_2 lower emissions and leads to cost relief of about 80 €.

In the case of lower certificate prices or (partial) free allocation, the effect could be lower.

In particular, attention is paid to the cost implications of different targets and different allowance prices. Also, the use of a discount factor and penalties is elaborated upon. Finally, the extent to which target setting or the allocation of allowances could be adapted is discussed (if it is considered that the costs for manufacturers acquiring allowances based on the deviation with specific targets would be too low to provide a sufficient incentive to improve technology).

8.3.1. ASSUMPTIONS USED

Although the exact design of linking car manufacturers to the EU ETS is not discussed in detail, some assumptions, which have been made are discussed below.

Car manufacturers would be made responsible for the potential emissions of the cars they sell. The potential emissions are estimated beforehand by multiplying the emissions per km (in g

CO_2/km) by an assumed lifetime mileage of 208.000 kms. The mileage is based on an assumed average lifetime of a passenger car of 13 years, and an average annual mileage of 16.000 kms, in line with TNO et al. (2006). It is assumed that a target is imposed on the car manufacturers, which holds for the type approval test. This target may be 130 g CO_2/km or some other figure. If the emissions of the car sold are higher, the car manufacturer will have to purchase allowances for the excess emissions over the lifetime of the car. If the projected emissions of the car sold are lower, the car manufacturer may sell allowances on the EU ETS market[85]. It is assumed that the surrender of allowances for the projected excess emissions over the whole lifetime of the passenger car will be required at the end of the year in which the car is sold.

In some cases, the above assumptions have been relaxed for sensitivity analysis. When this is the case, it has been explicitly mentioned together with how it has been done.

8.3.2. COST IMPLICATIONS, DIFFERENT DEVIATIONS FROM TARGET AND ALLOWANCE PRICES

The example given in section Section 8.2.6. and Section 8.3. above provides a very rough indication of the costs for car manufacturers if they were to be linked to the EU ETS. In general, if the target is not met by business as usual developments, car makers may react in a number of ways. For example, they may decide to improve the fuel efficiency of their cars, or to change the price setting of their production line so to make fuel efficient cars more attractive hence more will be sold. Alternatively, they may choose to purchase additional allowances on the EU ETS market. In this chapter, it has been assumed that car manufacturers will decide to purchase allowances for the projected excess emissions on the EU ETS market. Under this assumption, the cost implications per average passenger car sold can be estimated by the following formula:

Costs = deviation from the target x mileage x allowance price / 1.000.000, where

Costs:	required expenses[86] on allowances for the car manufacturer
Deviation from the target:	difference between fuel efficiency (expressed in g CO_2/km) of the car and the target
Mileage:	projected lifetime mileage
Allowance price:	price of allowances on the EU ETS market

---

[85] How this would be implemented exactly, is not discussed in this section. For a brief discussion on some of the practicalities and the difficulties this may entail, see section 8.3.7.

[86] Or the revenue from the sale of allowances if the fuel efficiency of the sold car is better than the target.

Using this formula, and assuming an allowance price of € 20 per tonne CO_2 and a lifetime mileage of 208.000 kms, the costs for several different deviations from the target can be estimated.

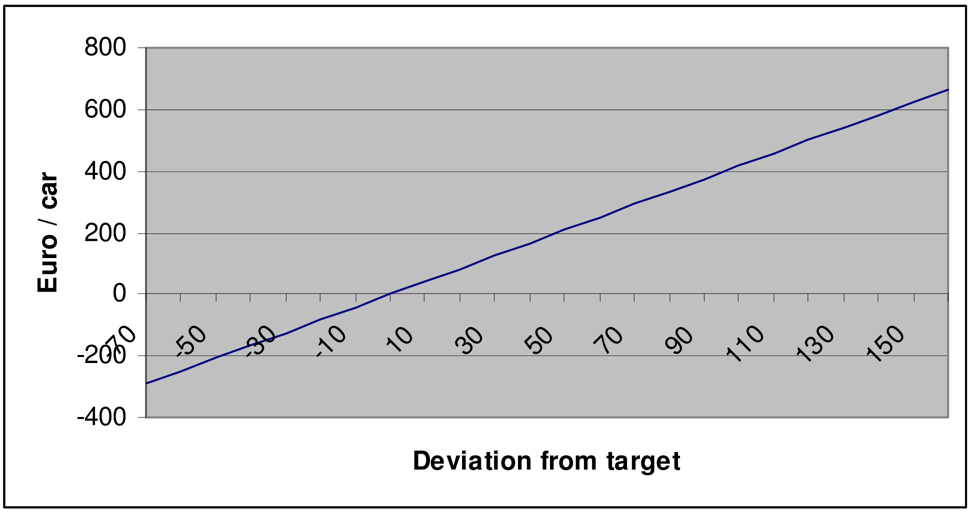


Figure 39 Expenditures on allowances for projected excess emissions (projected lifetime mileage = 208.000 kms, allowance price = € 20)

Figure 39 shows the direct relation between the deviation from the target and the costs per passenger car sold. As indicated by the formula, there is a linear relation between costs per car and the deviation from the target. For a car that emits 100 g CO_2 / km above the target, allowances will have to be purchased for a total of € 416 at the time of sale.

Similarly, using the above equation, the costs of deviating from the target for different allowances prices can be calculated. Again, there is a linear relation between the allowance price and the costs per car.

Figure 40 Expenditures on allowances for projected excess emissions (projected lifetime mileage = 208.000 kms, deviation from target = 30 g CO_2/km)

Figure 41 shows the joint impact of allowance price and deviation from the target on the costs.

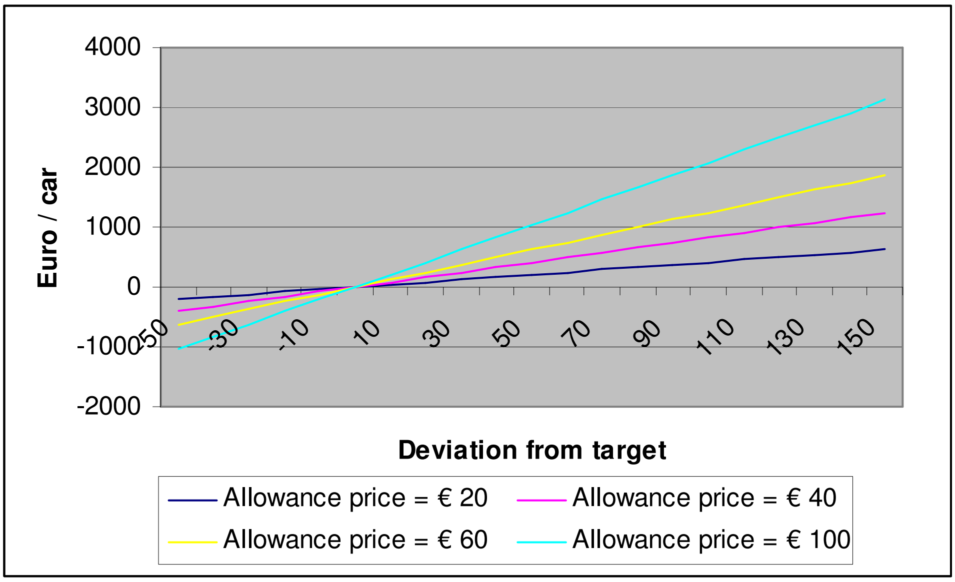


Figure 41 Expenditures on allowances for different deviations from target and different allowance prices (projected lifetime mileage = 208.000 kms)

Table 69 further lists the cost implications for allowance prices of € 20, € 40, € 60 and € 100 and deviations from target ranging from -50 g CO_2/km to + 150 g CO_2/km.

	Allowance price (€)										
Devia-tion from target (g CO$_2$/km)	0	10	20	30	40	50	60	70	80	90	100
-50	0	-104	-208	-312	-416	-520	-624	-728	-832	-936	-1040
-40	0	-83.2	-166.4	-249.6	-332.8	-416	-499.2	-582.4	-665.6	-748.8	-832
-30	0	-62.4	-124.8	-187.2	-249.6	-312	-374.4	-436.8	-499.2	-561.6	-624
-20	0	-41.6	-83.2	-124.8	-166.4	-208	-249.6	-291.2	-332.8	-374.4	-416
-10	0	-20.8	-41.6	-62.4	-83.2	-104	-124.8	-145.6	-166.4	-187.2	-208
0	0	0	0	0	0	0	0	0	0	0	0
10	0	20.8	41.6	62.4	83.2	104	124.8	145.6	166.4	187.2	208
20	0	41.6	83.2	124.8	166.4	208	249.6	291.2	332.8	374.4	416
30	0	62.4	124.8	187.2	249.6	312	374.4	436.8	499.2	561.6	624
40	0	83.2	166.4	249.6	332.8	416	499.2	582.4	665.6	748.8	832
50	0	104	208	312	416	520	624	728	832	936	1040
60	0	124.8	249.6	374.4	499.2	624	748.8	873.6	998.4	1123.2	1248
70	0	145.6	291.2	436.8	582.4	728	873.6	1019.2	1164.8	1310.4	1456
80	0	166.4	332.8	499.2	665.6	832	998.4	1164.8	1331.2	1497.6	1664
90	0	187.2	374.4	561.6	748.8	936	1123.2	1310.4	1497.6	1684.8	1872
100	0	208	416	624	832	1040	1248	1456	1664	1872	2080
110	0	228.8	457.6	686.4	915.2	1144	1372.8	1601.6	1830.4	2059.2	2288
120	0	249.6	499.2	748.8	998.4	1248	1497.6	1747.2	1996.8	2246.4	2496
130	0	270.4	540.8	811.2	1081.6	1352	1622.4	1892.8	2163.2	2433.6	2704
140	0	291.2	582.4	873.6	1164.8	1456	1747.2	2038.4	2329.6	2620.8	2912
150	0	312	624	936	1248	1560	1872	2184	2496	2808	3120

Table 69 Costs in € for different deviations from target and different allowance prices (projected lifetime mileage = 208.000 kms)

8.3.3. COST IMPLICATIONS FOR DIFFERENT MILEAGES

Assuming a deviation from the target of 30 g CO$_2$/km and an allowance price of € 20, the impact of the assumption on the lifetime mileage of the car can also be presented graphically. Figure 42 shows the costs in Euro per car for different lifetime mileages.

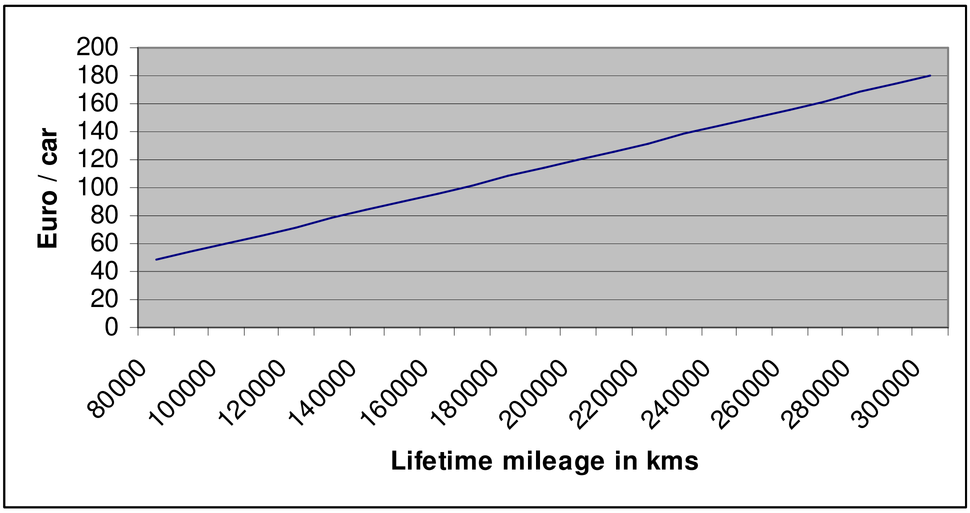


Figure 42 Expenditures on allowances for projected excess emissions (allowance price = € 20, deviation from target = 30 g CO_2/km)

8.3.4. DISCOUNT FACTOR

The graphs and data above are exclusive of a discount factor. Two arguments might be made for the inclusion of a discount factor. In the first place, a discount factor might be in place in case some of the expenditures take place in the future. To calculate the net present value of the costs of opening up the EU ETS to car manufacturers, a discount factor should then be applied. This will be discussed first.

In the second place, one might argue that if car manufacturers would be required to surrender allowances for the lifetime emissions of the car in the year of sale, a discount factor to the number of allowances might be appropriate. The reason being that part of the allowances that will be surrendered will relate to emissions that have yet to occur.

Discount factor for future payments

Whether a discount factor should be applied depends on the precise design of inclusion of the car manufacturers to the ETS. Following the assumption made in section 8.3.1. that allowance for the lifetime excess emissions have to be surrendered in the year of sale, no discount factor should be applied. Under an alternative design, a discount factor may be appropriate.

First of all, it should be noted that the application of a discount factor is different from correcting for inflation. A correction for inflation is appropriate if the expenditures over time are in prices of the year in which they take place. To make figures comparable, a inflation correction should be applied, transforming all figures in real terms[87]. A discount factor instead reflects the opportunity costs of capital of the time preference. An assumption that a car manufacturer is required to purchase 10 allowances at a real price of 20 Euro each in 5 years time would entail an expenditure of 10 * 20 = 200 Euros. However, in the 5 years leading up to the moment the car manufacturer is required to purchase and surrender the allowances, the capital can be invested productively. Conseuently, in order to have 200 Euros in five years time, potentially only, say, 165 Euros are required now.

For the purpose of determining whether applying a discount factor would be appropriate in the case of linking car manufacturers to the EU ETS, two possibilities are distinguished between. First, car manufacturers may be required to answer to the estimated total CO_2 emissions of the vehicle over its lifetime at the moment (or in the year) the vehicle is sold (in line with the assumption made in section 8.3.1.). The second possibility is that for each year the car is in service, the car manufacturers will answer in that particular year, based on a predetermined estimate of the mileage of the car for each of the years it is in service.

In the first case, application of a discount factor would not be appropriate. All the costs of applying to the new regulation befall in the year the car is sold, so there are no future expenses to apply a discount factor to.

If the expenditures of car manufacturers selling a particular car fall partly into the future, a discount factor should be applied to estimate the net present value of these expenditures. The Commissions guidelines for Impact Assessments (European Commission, 2006) indicate that a 4% discount factor in real terms should be applied.

Based on the examples above, the costs could be determined in case car manufacturers are required to surrender allowances in each particular year the car is assumed to be used. It is assumed that the hypothesized mileage of the car is distributed evenly over each year it is assumed to be in service. It is also assumed that the allowance price (in real terms) is constant over the lifetime of the car[88], and is € 20 per tonne CO_2. For a car that emits 30 g CO_2 / km above the target, the total discounted costs would then be € 99.70. The expenditures on allowances in the first year would be 30 x 16.000 x 20 / 1.000.000 = € 9.60. The costs of the expenditures in the

---

[87] For a further discussion of discount and interest rates, see for example EEA, 1999, Guidelines for defining and documenting data on costs of possible environmental protection measures; Technical report no. 27, European Environment Agency, Copenhagen, 1999.

[88] Clearly, these assumptions cannot be considered as fully realistic although atb this stage there is not sufficient information available to speculate on the future pruicing of CO2 alowances. The assumptions sued do, however, serve the purpose of illustrating the potential impact of applying a discount factor.

second year would be this amount divided by 1.04. For the net present value of the expenditures in the third year, one needs to divide € 9.60 by the square of 1.04 etc.

The net present value of € 99.70 can be compared to the amount of € 124.80 for a scheme in which all allowances would have to be surrendered in the year the car is sold.

Discount factor for advance surrendering

It could be argued that if car manufacturers are required to surrender allowances for the lifetime emissions of the car in the year of sale, a discount factor to the number of allowances might be appropriate. The argument would be that part of the allowances that are surrendered will relate to emissions that have yet to occur.

As can be concluded from the previous section, the net present value of expenditures is higher for car manufacturers under a scheme where they are made to purchase all allowances in the year of sale[89], provided that the allowance price stays constant.

However, whether a discount factor should be applied to advance surrendering relates to the environmental integrity of the scheme. As is further elaborated later, the inclusion of car manufacturers on the basis of accounting for lifetime vehicle emissions is a marked deviation from current practice under the EU ETS. Assuming that such a link could nonetheless be made, the application of a discount factor does not appear to be appropriate.

The idea behind emissions trading is that for each tonne of CO_2 emitted by an installation under the scheme one allowance is surrendered[90]. At the end of the year, the total number of surrendered allowances should match the total CO_2 emissions. This ensures the environmental integrity of the scheme. The environmental integrity is a key characteristic to emission trading and will also need to be ensured if car manufacturers are incorporated into the EU ETS through advance surrendering. It does not appear that this would leave room open for discounts for advance surrendering. Also for car manufacturers, there would be the requirement that allowances surrendered should match emissions, albeit over a longer time period.

The possibility that advance surrendering would actually reduce the environmental impact of CO_2 emissions also needs to be considered. In the case of car manufacturers, advance surrendering would mean that for each allowance surrendered, the CO_2 emissions associated with it

---

[89] Or similarly, that the net present value of the benefits from the sale of allowances associated with a vehicle that has better fuel efficiency than the target is higher if they are allowed to sell these allowances in the year of sale of the vehicle.

[90] Or, more correctly, for each tonne of CO_2-equivalent.

are postponed by on average about 6,5 years[91], compared to the situation where the allowance was surrendered by ‘regular’ entity under the scheme, assuming a constant cap. It is hard to quantify the environmental benefit of this postponement, if any. The lifetime of CO_2 in the atmosphere is in the order of a century. Most of the ‘damage’ caused by the emitted CO_2 takes place years in the future. Recent estimates of the damage costs of CO_2 emissions are increasing over time: the damage costs associated to emission of a ton of CO_2 is higher if it is emitted at a later date, see HEATCO (2006). Therefore, at the moment there appears to be little justification for applying a discount factor for advance surrendering, although this issue merits further analysis.

8.3.5. COSTS OF EMISSION TRADING

This section briefly discusses the costs that emission trading for car manufacturers would entail. Approximate measures are applied to derive an indication of the costs and more analysis is required to draw more precise conclusions.

The total costs are analysed for one particular year: 2012. For the cars sold during that year, the costs for car manufacturers for making the cars more fuel efficient or for purchasing allowances have been estimated. For this purpose, it will first be considered to what extent the response of car manufacturers can be expected to purchase allowances. As an alternative, they may, for example, decide to improve the fuel efficiency of the passenger cars they produce.

Costs of improving fuel efficiency

Based on the analysis in the previous chapter, it can be established what the incentive for car manufacturers is to reduce the fuel efficiency of a car by 1 g CO_2/km. This incentive depends on the assumed life time mileage and the price of allowances as follows:

Incentive per gram/km fuel efficiency = mileage x allowance price / 1.000.000

If it is assumed, in line with the analysis above, that the average mileage is 208.000 kilometres (vehicle life time of 13 years, and annual mileage of 16.000 kms) and the allowance price in 2012 is € 20, the incentive car manufacturers have to improve the fuel efficiency of a vehicle by

---

[91] This is half the assumed lifetime of the vehicle. Assuming a stable annual mileage of 16.000 kms, emissions will ‘on average’ occur 6,5 years after the date the car was sold. On average, cars are sold halfway during the year, so emissions take place on average six years after the associated allowances have been surrendered. However, had the allowance been surrendered for the emissions of a ‘general’ installation under the scheme, they would ‘on average’ have been surrendered half a year after emissions took place. So by purchasing the allowance and surrendering it to cover the emissions of a vehicle, emissions are on average postponed by six years.

1 g CO_2/km can be estimated. This incentive would equal € 4,16. This estimate depends linearly on the assumed mileage and the assumed allowance price. For example, at an allowance price of € 40 per tonne of CO_2, the incentive would be € 8,32. The table below presents the costs for different allowance prices assuming an average mileage of 208.000 kms.

Allowance price	0	10	20	30	40	50	60	70	80	90	100
Incentive	0	2,08	4,16	6,24	8,32	10,40	12,48	14,56	16,64	18,72	20,80

Table 70 Incentive per gram/km fuel efficiency for different allowance prices

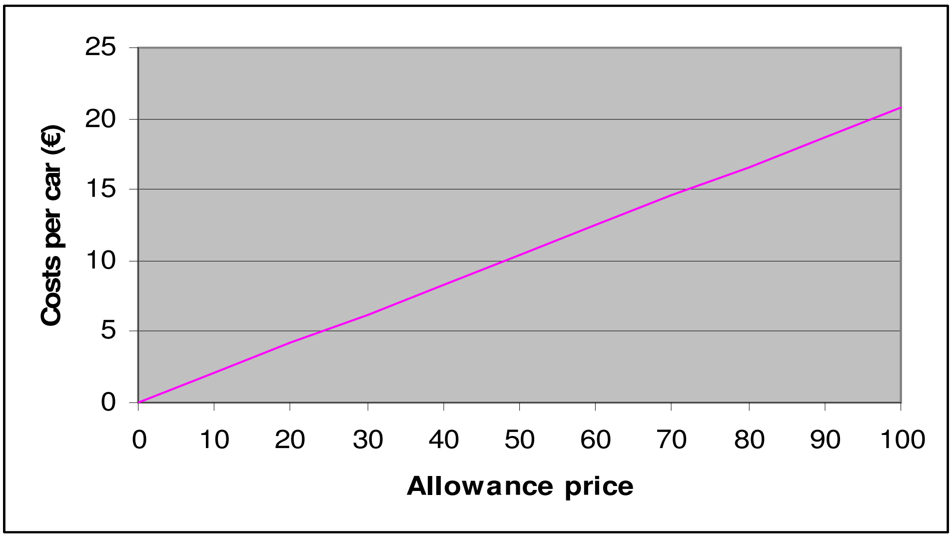


Figure 43 Incentive per gram/km fuel efficiency for different allowance prices

On the basis of TNO et al. (2006), the costs for car manufacturers to reduce fuel efficiency beyond the 2008/9 target of 140 g CO_2/km are in the order of € 25 to € 100 per g CO_2/km. It may therefore be assumed that the majority of car manufacturers would not deploy additional measures to improve fuel efficiency, but would decide to purchase allowances on the ETS market instead[92]. In estimating the total costs for the automotive industry, this assumption will be used.

In addition to this analysis, Table 71 provides further insight into the relative costs of the different options. For different specific targeted improvements in fuel efficiency, the costs of

---

[92] This is obviously based on the assumption that CO2 reduction is the sole motivation for car manufactueres to improve the fuel efficiency of their vehicles.

purchasing allowances are compared to the costs of technically increasing the fuel efficiency of the car itself. For this comparison, it has been assumed that either allowances are bought in full on the EU ETS market (and no technical improvements are made), or the target is achieved by technical improvements only[93].

The costs of technological improvements are based on from TNO et al. (2006). The additional manufacturer costs of reducing the average fuel efficiency from 166 g CO_2/km in 2002 to 140 g CO_2/km in 2008/9 were estimated at € 832 per vehicle (translating in an average increase in retail price of € 1.200). The additional costs for the manufacturers of maintaining this average fuel efficiency until 2012 were estimated by TNO et al. (2006) at € 210. Total manufacturer costs of achieving an average target of 140 g CO_2/km by 2012 down from an average of 166 g CO_2/km in 2002 are thus estimated at € 832 + € 210 = € 1.042. Similarly, the costs for the other targeted improvements have been estimated on the basis of TNO et al. (2006).

	Allowance price (€)			Manufacturer cost of technological improvement (€)
Targeted improvement	20	40	60	
166 -> 120	191	382	574	2.501
166 -> 130	150	300	449	1.655
166 -> 140	108	216	324	1.042

Table 71 Comparison of the costs per car of different options to meet fuel efficiency target

For all scenarios assessed, the costs for manufacturers are higher if they are not included in the EU ETS and improvements have to be achieved within the sector.

Car sales and fuel efficiency developments

To determine the total costs for the industry, it is also required to have an estimate of the total registrations of new vehicles for 2012. Table 72 reports the official data on car sales and average fuel efficiency for 2004.

---

[93] If the EU ETS market is opened to car manufacturers, a mixture of purchasing allowances and improving technology is the logical outcome. However, as we have seen above, the costs of improving technology are much higher than those of purchasing allowances, and the impact of this simplification is very small.

	2004 monitoring data of EU 15		2004 monitoring data of EU 10		2004 monitoring data of EU 25	
Fuel	Registrations	g CO_2/km	Registrations	g CO_2/km	Registrations	g CO_2/km
Petrol	7.001.245	170	533.665	158	7.534.910	169
Diesel	6.787.834	155	168.284	151	6.959.118	155
Petrol + diesel	13.789.079	163	701.949	156	14.491.028	162

Source: COM(2006) 483

Table 72 Fuel efficiency of newly registered passenger cars

In the EU 25, about 14,5 million passenger cars were registered in 2004. For the purpose of estimating total costs to the automotive industry, a forecast of the number of new registries for the year 2012 is needed. Assuming a yearly growth factor of about 1%, in line with historic growth factors, there would be about 15,5 to 16 million new registries in 2012[94]. The figure of 16 million in will be used for the calculations.

An assumption about the business as usual fuel efficiency of newly registered cars in 2012 is also needed. It is assumed that the target of 140 g CO_2 / km is achieved in 2008/9 and that this will remain stable for the period up to 2012.

Expenditures of car manufacturers

The total expenditures of car manufacturers on allowances in the year 2012 can now be estimated. Assuming a deviation of 20 grams per kilometre from the 120 g/km target, based on the analysis above, € 83.2 worth of allowances would have to be surrendered at the year of sale for the average passenger car.

Therefore the total expenditures by car manufacturers would be in the order of 16.000.000 x € 83.2 = € 1.3 billion for the year 2012 only. Two things should be kept in mind when looking at this figure. First, it should be noted that it is a very rough estimate, based on a number of crucial assumptions, which may in practice be met or not. In addition, it is very important to note that this figure indicates the potential expenditures of car manufacturers on allowances. It has not been analysed whether car manufacturers may be able to pass through these costs to their buy-

---

[94] Note that this figure is not very sensitive to higher growth factors for the EU 10. Assuming a growth factor of 1% for the EU 15, and a factor of 5% for the EU 10, would lead to about 16 million new registries in 2012.

ers. If that would be the case, next to the expenditures on allowances, they would have higher revenues from the higher market prices of passenger vehicles. If car manufacturers would be able to pass through (part of) the expenditures on allowances, the amount of € 1.3 billion does not provide any indication of the loss of revenue or profits to car manufacturers due to the linkage to the EU ETS. The extent to which car manufacturers would be able to pass through the expenditures on allowances would require a separate study and has not been analysed here.

Another point worth noting is that following the assumptions above, the car manufacturers would demand on the EU ETS market in 2012 a total of about 66.5 Mton of allowances. Such an additional demand on the EU ETS market may affect the equilibrium price of allowances on the market. Whether this would be the case depends on the shape of the supply curve for allowances. This in turn depends in part on the extent to which credits from CDM and JI will be allowed to enter the market. This has not been studied further.

Would the BaU not be 140 g CO_2 / km in 2012, but 155 instead, then the total expenditures by car manufacturers would be about € 2.3 billion.

Societal costs

The comparison of the potential costs of purchasing allowances to the forecast costs of improving fuel efficiency of passenger cars indicates that it is likely that car manufacturers will opt for the former option, since it is expected to be much cheaper. The societal costs of purchasing allowances on the EU ETS market have not been calculated in detail due to the scope of this study. It cannot be easily determined which emission reduction measures will be taken, and what the societal costs of these measures will be.

It can be expected that the first order costs to society will be in the same order of magnitude as the additional expenses of the car manufacturers. To determine the extent, to which these costs in fact befall the European society, would require a much more extensive analysis. For example, it would need to be determined to what extent the non-European car manufacturers would be able to pass on their costs to the European car buyers[95]. Also, it would need to be determined to what extent the additional demand on the EU ETS market would be met by additional credits from CDM and JI[96].

---

[95] For example, if a US car manufacturer would not be able to pass through the expenditures on allowances, there would be no direct costs to the European society.

[96] Such credits would entail a transfer of money from the European society to firms located in countries outside of Europe. Therefore costs to the European society. If on the other hand, additional emission reduction measures would be taken inside of the EU, only part of the expenditures would entail costs to society.

8.3.6. PENALTIES

In general, policy measures include a penalty system to ensure compliance. Here a brief discussion has been undertaken on how application of the EU ETS to the transport sector with car manufacturers as liable actors could be linked to penalties for not complying with the specific targets. The enforcement of the penalty system is a different matter, which will not be discussed.

First the current penalty system incorporated in 2003/87/EC (European Commission, 2003) is discussed. There is also a brief discussion of of the linkage between emission trading, price caps under emission trading systems and penalties for non-compliance.

Penalties under Directive 2003/87/EC

Article 16 of the emission trading directive relates to penalties for non-compliance. Member States are to lay down the rules on the penalties applicable. The penalties are required to be effective, proportionate and dissuasive. Sub 3 of article 16 specifies that operators who do not surrender sufficient allowances by 30 April of each year to cover its emissions during the preceding year are held liable for the payment of an excess emissions penalty. This excess emissions penalty is € 100 for each tonne of carbon dioxide equivalent emitted by that installation for which the operator has not surrendered allowances. Payment of the penalty does not release the operator from the obligation to surrender an amount of allowances equal to these excess emissions when surrendering allowances in relation to the following calendar year. Sub 4 of the article specifies that for the three years 2005 – 2007, the penalty will be set at € 40. So the operator receives a penalty of € 100 (€ 40 in 2005 – 2007) and needs to hand in allowances for the excess emissions the next year.

In all likelihood, if car manufacturers would be linked to the EU ETS, they would face a similar penalty as the other entities under the EU ETS.

Penalties as a safety valve

Jacoby & Ellerman (2004) note that in general, under a cap & trade emission trading scheme, penalties may be regarded as a safety valve. If the price of emission allowances on the market increases to a value above the penalty, operators will opt to pay the penalty instead of complying by purchasing additional allowances. They may even opt for selling allowances at the market price, and pay the penalty instead.

As such, emission trading and penalties (or emission charges) thus become two endpoints of one gliding scale. If the penalty is set low, operators will pay the penalty, which may then be regarded as an emission charge. In contrast, if the penalty is set high, there will be emission trading.

It should be noted that this does not hold for the EU ETS, since apart from paying the penalty, non-compliant operators are required to surrender allowances for the excess emission in the next year.

8.3.7. FURTHER ANALYSIS

This section discusses to what extent the target setting or allocation of allowances could be adapted, if it is considered that the costs for manufacturers acquiring allowances based on the deviation with specific targets would be too low to provide an incentive to improve technology.

First, the analysis in section 8.3.5 compares the financial incentives provided by the costs for manufacturers to increase fuel efficiency of vehicles. The conclusion from this comparison is that the incentive provided by the linkage to the EU ETS is well below the costs of improving the fuel efficiency of passenger cars.

Irrespective of this comparison, the adjustment of target setting or the allocation of allowances will not increase the financial incentive to car manufacturers to improve technology. The reason is as follows. Given the inclusion of the car manufacturers to the EU ETS, they will be incentiviced to sell (and develop) more fuel efficient cars. Irrespective of the specific target, or the allocation method, the incentive for every g CO_2/km improvement of fuel efficiency is directly related to the price of allowances on the market. Improving the fuel efficiency by one g CO_2/km will either mean that the car manufacturer has to purchase fewer allowances, or will mean the manufacturer can sell more allowances.

This does not depend on the target set, nor on the allocation methodology. The incentive comes primarily from the opportunity costs of allowances. Whether allowances are allocated freely, or need to be purchased in full at an auction, in fact, even in case twice the amount of allowances required by the manufacturers would be allocated to them, the incentive to sell and produce more fuel efficient cars would not change. The incentive is provided by the overall cap (this will determine the market price of allowances) and the inclusion of the car manufacturers in the scheme. How allowances are distributed among the different parties under the scheme is essentially a question of fairness and does not affect the efficiency of the scheme, nor the incentives it provides[97].

---

[97] Note that at a more aggregate level, the allocation method may affect the efficiency of the scheme. This does not relate so much to the specific question answered here, and goes into too much detail to discuss at length in this contribution. The point is that under 'updated' or 'repeated' benchmarking, there will be reduced incentives to re-

Relation with directive 2003/87/EC

In this section the potential linkage of car manufacturers to the EU ETS and how this may affect the EU ETS is briefly iscussed.

Linking car manufacturers to the EU ETS on the basis of the estimated CO_2 emissions over the lifetime of the vehicles sold would require careful consideration. In some aspects, this would represent a marked deviation from current practices under directive 2003/87/EC. In addition, it requires addressing several questions regarding practical matters.

In particular, 2003/87/EC regulates, to the extent possible and with the use of flexible mechanisms, the actual emissions of CO_2 of the installations covered by the directive. At the end of each year, allowances need to be surrendered for the emissions during that year. It is the operators of the installations that produce emissions, that are required to surrender allowances. These operators have the most options for reducing emissions, including reducing the hours of operation of the installation. Finally, directive 2003/87/EC has in part been developed to answer to the European Community's emission reduction obligations under the UNFCCC framework.

A linkage of car manufacturers to the EU ETS on the basis of the hypothesized lifetime emissions of the vehicle sold would represent a deviation from current practices. In the first place, the current EU ETS is a cap & trade system. Total emissions under the scheme are capped, allowances are allocated to the different entities up to the total cap, and the entities can trade so as to reduce allowances where it costs least. The linkage to car manufacturers as studied here would mean linking a cap & trade scheme with a relative scheme. The total emissions of new passenger cars would not be capped. If more new cars would be sold, the total emissions under the scheme would increase.

Second, car manufacturers are not the operators of the cars, and many means for reducing emissions from cars would not be rewarded under such a scheme. For example, driving less, driving more efficient and increasing the load factor of a vehicle are all means to reduce the emissions from passenger cars that would not be incentivised by the scheme. In fact, the scheme would not provide any incentive (additional to the current market incentives) to trade in an old and fuel inefficient car for a more fuel-efficient one, whereas from an environmental perspective, this may be a very cost-effective way to reduce emissions.

Third and fourth, in contrast to the current EU ETS where the actual emissions are estimated / calculated, a scheme based on the vehicles sold would most likely need to rely on a very rough

---

duce emissions (or sell fuel-efficient cars) in the year that serves as base year for the future allocation period. See for example Grubb & Neuhoff (2006).

estimate of the annual or lifetime mileage of the car. It may be difficult to develop a methodology to estimate at the moment of sale a car's lifetime emissions, in a way that would be in correspondence to the obligations under the UNFCCC. So, the method for estimating emissions is not as precise as under the current EU ETS and, in addition, this may cause problems with answering the obligations under the UNFCCC.

In the fifth place, under the current EU ETS, the allowances handed in at the end of a particular year match the emissions during the year. If car manufacturers were to purchase allowances for the total lifetime emissions of the car sold, in the year it is sold, allowances surrendered will no longer match the emissions during the year.

The points listed above have not been pursued in detail in this study. Similarly it is not possible at this stage to properly assess the feasibility of a scheme linking car manufacturers to the EU ETS. The issues outlined above provide a brief and non-exhaustive overview of the elements that need to be addressed further if the option of linking car manufacturers to the EU ETS is to be pursued further.

8.4. NEXT ANALYTICAL STEPS FOR AN EXTENSION OF ETS TO ROAD

Different approaches of an emission trading in the transport sector have been presented in the study. The advantages and disadvantages of the different approaches need to be evaluated by the Commission in order to decide upon the political feasibility including strategic objectives (like "trading emissions" vs. "trading standards"). However, a final decision might need more information on details with regard to implementation (details of institutional structure, responsible authorities, availability of data, legal framework, and detailed assessment of transaction costs, linking standards and absolute emission levels etc.). In addition to the closed and open approach another solution could be further explored, which would link the system through the Flexible Mechanisms (Joint Implementation and Clean Development Mechanisms).

A workshop with stakeholders would be very helpful, leading to insights about additional chances and barriers of the discussed approaches. A pilot phase or pilot project would be another option to gain first experiences for an emission trading in the transport sector. In addition experiments based on experimental economics could be undertaken to test specific implementation scenarios before implementing them in reality.

Furthermore, an assessment of the MAC curves needs to be undertaken based on the timeframe in which the Commission would consider applying emissions trading to the road transport sector (e.g. the period after 2012) together with an in-depth assessment of the design parameters for the preferred system. In addition, it seems also worthwhile to analyse in more detail possible impacts on innovation and competitiveness of the European car industry (short-term and long-term) and emission reduction (considering price elasticity).

GLOSSARY

General terms, for all sectors

AD	Anaerobic Digestion
AirCo	Air Conditionin
Base year	For this study: 1990 The first year of a time series considered, either of a statistical series of the past (in our case 1990 to 2003), or for a perspective into the future (in our case 2003 to 2008-2012). In the literature the terms initial year or reference year are sometimes used as synonyms.
BAT	Scenario using the best available technologies
BAU	Business as usual (for scenario without any reduction measures at all)
BEMS	Building Energy Management Systems
BTL	Biomass to Liquid
CAP	Common Agricultural Policy of the EU
Carbon leakage	The ratio of Kyoto policy induced increase of GHG emissions from non-abating (non-Annex B) countries over the reduction of emissions by abating (Annex B) countries.
CER	Certified emission reduction
CFCs	Chlorofluorocarbons
CH_4	Methane
CHP	Combined Heat and Power production
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_{2eq} / Mtonnes CO_{2eq}	Carbon Dioxide equivalents / Million tons of CO_2 equivalents
Degree of implementation (DoI)	The degree to which a PAM is (expected to be) implemented until 2008/ 2012. e.g. considering car retrofitting measures, in % of the cars concerned (all cars in operation), or, for tyre pressure monitoring equipment for new cars coming on the market.
DI	Direct injection
DPF	Diesel Particle Filter (trap)
EEA	European Environment Agency
EGR	Exhaust Gas Recirculation
Emission reduction (Mtonnes/a)	Emission reduction rates per year. They are always expressed as CO_2 equivalent

ETC/ACC	European Topic Center for Air and Climate Change
ETS	Emission trading system
EU10	The 10 “new” member states
EU15	The EU with the 15 “old” member states
EU23	Eu25 less Malta and Cyprus (these 2 states are not Annex B countries and have no Kyoto reduction commitment)
EU25	EU with all 25 member states in 2006
Euro-1, -2, -3, -4, -5	European exhaust standards for light and heavy motor vehicles
FAME	Fatty Acid Methyl Ether
FDC	Fixed displacement compressor
FTRL	Frozen Technology Reference Level, as used by Blok et al. (2001a). The FTRL of Blok’s bottom-up analysis of emission reduction potentials and costs for GHG does not include autonomous energy efficiency improvements, technological progress, changes in the production structure of the society, or the effects of current policies.
G0, G1	Gaps (in Mtonnes/a) to the fulfilment of the Kyoto commitment, for the scenarios S0, S1 and ΔS1-2 respectively.
GHG	Green House Gases: i.e. CO_2, CH_4, N_2O, HFCs, PFCs and SF_6
GSI	Gear Shift Indicator
GTL	Gas to Liquid
GWP	Global Warming Potential of the GHG: i.e. the factor 1 for CO_2, 21 for CH_4, 310 for N_2O, 140 to 11'700 for HFCs, 6’500 to 9'200 for PFCs and 23’900 for SF_6.
H2	Hydrogen
HCCI	Homogeneous Charge Compression Ignition
HDV	Heavy Duty Vehicle: vehicle for road transport with a maximum allowed gross vehicle weight (including payload) of equal or more than 3.5 tons
HFCs	Hydrofluorocarbons
ICAO	International Civil Aviation Organisation
IMO	International Maritime Organisation
Kyoto Commitment period	2008-2012

LDV	Light duty vehicle
Lead study	The study identified as the one with the most complete, coherent and up to date one for the extraction of sectoral MAC data, based on bottom up analysis. Other studies and literature will be used to amend, complement, or adapt the results where needed, and to cross-check for purposes of sensitivity analyses and considerations. Wherever possible, data will be drawn from the lead study. On the basis of the first literature search (identification and abstracting), INFRAS has identified Blok et al. (2001a and b) as the lead study.
LRRT	Low rolling resistance tyres
LULUCF	Land use, land use change and forestry
LVL	Low viscosity lubricants
M, M$, Mtonnes	Million, Million $, Million tons (= Megatons)
MAC	Marginal Abatement Cost for a particular measure, always expressed as €/t
Mobile AirCo	Mobile Air Conditioning systems
Maximum theoretical potential	Average reduction of emissions per year in the time range 2008 to 2012 or in the year 2020 due to a measure [tons CO_{2eq}/year]. The potential always gives the total reduction within EU 25 (or EU 15) and not the potential for single new ve-hicles. The potential for technological measures applied to new vehicles is much lower if related to the total HDV traffic in EU 25 than the potential for the single new vehicles since the fleet penetration with new vehicles will by far not be finalised until 2008 due to a measure starting earliest in 2007. In the maxi-mum theoretical potential the measure is introduced to 100% of the theoretically possible maximum (either 100% of new registered vehicles or 100% of all suited vehicles in the fleet).
Measure	Physical or behavioural measures undertaken by socio economic actors as a response to the policy instruments issued by politics. (in our case: measures to reduce the GHG emissions of the economic activities toward which the policy is addressed, e.g. a certain sector in a certain member state, and/ or in the EU as a whole)
Mtonnes/a	Million tons per year
MTB	Mechanical Biological Treatment: This option means an aerobic degrading of the whole waste stream and landfilling of the solid residue (like dry stabilisation).
N1 vehicles	Light commercial vehicles

N_2O	Nitrous oxide
NEDC	New European Driving Cycle
NGCC	Natural Gas Combined Cycle
NSC	Non-Structural Carbohydrates
PAM	Policies and measures: each PAM has a MAC associated with it.
NTE	Not To Exceed limits for real world driving
PAM0+	Planned policies and measures beyond the baseline (scenario 0)
PAM1+	Additional policies and measures (generally for EU25) beyond the planned measures of scenario 1 (S1).
PAM1+ETS	Additional policies and measures beyond the scenario 1, with only EU ETS PAMs.
PC	Personal Cars
PFCs	Perfluorocarbons
PM	Particulate matter
Policy	The political /public incentive instrument to induce socio economic actors to undertake measures which contribute toward meeting political objectives (in our case Kyoto commitments).
Reduction potential (Mtonnes/a)	The amount of GHG reduction (in t $CO2/a_{equiv}$. or in % of the emissions without the measure), i.e. The reduction potential (e.g.) for a particular PAM, considering the limited time for implantation until 2008/2012 and the related degree of implementation. Calculated from the maximum theoretical potential but includes a level of implementation. This level of implementation takes into consideration that exploiting a potential to 100% is often impossible, especially in the short time frame until 2008. E.g. 100% of the HDV drivers could be trained for “eco-driving” and 100% of them could then use this driving style in theory until 2008. In reality these figures will not be reached without drastic and durable pressure.
RFD	Refuse Derived Fuel
RME	Rape methyl ester
RW	Real world (driving)
S	GHG Scenarios show the EU wide Emissions (in Mtonnes CO2 equiv/a) between 1990
S_{ETS}	Scenario S2 plus the effects of the extension of the EU ETS to road

	transport
S0	GHG scenario (generally for EU25) including PAMs in place = base-line scenario
S1	GHG scenario (generally for EU25) including PAMs in place plus those planned.
S2	GHG scenario 2: scenario where the Kyoto target of -8% for EU 25 should be achieved (not elaborated in detail)
S_6 / SF_6	Sulfur hexafluoride
SCR	Selectiv catalytic reduction
SME	Sunflower methyl ester
t	Ton= (for Emissions)
TA	Type approval
Technology potential	Potential reduction of emissions if a technology is introduced to a vehicle [% CO_{2eq}/ton-km]. The technology potential here is always given in % reduction compared to the average EURO III technology, i.e. without exhaust gas after treatment and with very small shares of HDV equipped with EGR but with cab roof deflectors for most HDV in long distance driving (truck-trailers and semi trailers).
TEHG	German Greenhouse Gas Emissions Trading Act
TPMS	Tyre pressure monitoring system
TTW	Tank-to-wheel: direct emissions
UNFCCC	United Nations Framework Convention on Climate Change
VDC	Variable displacement compressor
VFA	Volatile Fatty Acids
WTT	Well-to-tank: emissions from the fuel chain
WTW	Well-to-wheel: sum of TTW and WTT resulting from the mining and transport of raw energy carriers, the production and distribution of fuels and the consumption of fuel in the vehicle

LITERATURE

ADAS 1998: Effectiveness and feasibility of cost measures to reduce methane emissions from livestock in the EU. Report prepared for AEA Technology.

AEA 2001: Economic evaluation of emissions reductions for the transport sector if the EU, Bottom up analysis, J. Bates et al., AEA Technology Environment, March 2001, part of the "Blok-study" Economic evaluation of sectoral emission reduction objectives for climate change, by Ecofys Energy and Environment, AEA Technology Environment and National Technical University of Athens on behalf of DG-ENV.

Bates and Haworth 2001: Economic Evaluation of Sectoral Emission Reduction Objectives for Climate change: Economic Evaluation of Emission Reductions of Methane in the Waste sector in the EU. Bottom-up analysis. Final report (updated version), AEA Technology Environment, March 2001

Bates J. 1998: Options to reduce Nitrous Oxide Emissions (Final Report). A Report produced for European Commission DG XI under contract no. B7-8110/94/959/Mar/D4 (ExB4) – Emissions Inventories of Greenhouse Gases and Ozone Precursors.

Bates J. 2001: Economic Evaluation of Sectoral Emission Reduction Objectives for Climate change: Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU. Bottom-up analysis. Contribution to a Study for DG Environment, European Commission by Ecofys Energy and Environment, AEA Technology Environment and Naturional Technical University of Athens, Final report (updated), http://europa.eu.int/comm/environment/enveco/climate_change/agriculture.pdf, Abingdon/UK, February 2001.

Bates J., Brand C., et al. 2001: Economic Evaluation of Emissions Reductions in the Transport Sector in the EU, Final report (updated version) AEA technology Environment; 2001.

Betz 2006: Betz, R.: Emissions trading to combat climate change: The impact of scheme design on transaction costs. Centre for Energy and Environmental Markets, www.ceee.unsw.edu.au.

Blassnegger J. 2005: Emissionsminderungspotenziale durch optimierten Biodiesel und nachrüstbare Abgasnachbehandlung; Dissertation am Institut für Vkm und Thd, Graz 2005.

Blok et al. 2001a: Blok K., Hendriks C., de Jager D., de Beer J., Harnisch J., Joosen S., Phylipsen D., Kerssemeeckers M., Byers C., Patel M. (ECOFYS Energy and Environment), Bates J., Brand C., Davison P., Haworth A., Hill N. (AEA Technology Environment): Economic Evaluation of Sectoral Emission Reduction Objectives for Climate change: Bottom-up analysis of Emission Reduction Potentials and Costs for Greenhouse

Gases in the EU (updated). Summary report on results of the bottom-up analysis, Utrecht/NL, March 2001. http://europa.eu.int/comm/environment/enveco.

Blok K., de Jager D. and Hendriks C. 2001b: Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change: Summary Report for Policy Makers (updated), Utrecht/NL, March 2001.

Blok K., de Jager D., Hendriks C., Kouvaritakis N. and Mantzos L. 2001c: Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change – Comparison of 'Top-down' and 'Bottom-up' Analysis of Emission Reduction Opportunities for CO2 in the European Union, Ecofys Energy and Environment, National Technical University of Athens.

Bouwman A. 1990: Editor: Soils and the Greenhouse Effect, John Wiley & Sons.

Burton C. et al. 1993: The Effect of Continuous Aerobic Treatment on the Fate of the Nitrogen in Piggery Slurry, in Nitrogen Flow in Pig Production and Environmental Consequences Symposium Proceedings, Wageningen 8-11 June 1993, EAAP publication 69:404-409.

Burton C. et al. 1997: Manure Management: Treatment Strategies for Sustainable Agriculture published by Silsoe Research Institute and funded by the EU.

Cames et al. 2004: Cames M., Deuber O. and Rath U.: Emissionshandel im internationalen zivilen Luftverkehr. Institute for Applied Ecology for the German Federal Environmental Agency (UBA).

CCAP 2000: Winkelman S., Hargrave T. and Vanderlan C.: Transportation and Domestic Greenhouse Gas Emission Trading. Center for Clean Air Policy (CCAP). Washington D.C.

CE 2002: Wit R. and Dings J.: Economic incentive to mitigate greenhouse gas emissions from air transport in Europe. CE Delft for the European Commission.

CE 2005: Wit R. C. N., Boon B. H., van Velzen A., Cames M., Deuber O. And Lee D. S.: Giving wings to emission trading. Inclusion of aviation under the European emission trading system (ETS): design and impacts. Delft.

Chalupa E. 1988: Manipulation of rumen fermentation. In: Recent Developments in Ruminant Nutrition 2. Haresign W and Cole D J A (Eds), London: Butterworths, 1-18.

Chambers B. et al. 1999: Predicting nitrogen availability and losses following application of organic manure to arable land: MANNER. Soil Use and Land Management (1999) 15, 137-143.

Colbourn P. 1993: Limits to De-nitrification in Two Pasture Soils in a Temperate Maritime Climate, Agriculture, Ecosystems and Environment 43, 49-68.

Concawe 2006: Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, Concawe / Eucar / JRC, update of the 2003 study, January 2006.

de Beer J. and Phylipsen D. 2001: Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change – Economic Evaluation of Carbon Dioxide and Nitrous Oxide Emission Reductions in Industry in the EU Bottom-up Analysis, Ecofys (The Netherlands) and AEA Technology Environment (UK).

DEHSt 2006: Ausgabenstruktur der Deutschen Emissionshandelsstelle. http://www.dehst.de/cln_007/nn_387708/DE/DEHSt/Finanzierung/Ausgabenstruktur/Ausgabenstruktur__node.html__nnn=true

DLR et al. 2004: Nitsch J., and 11 other authors (DLR (co-ordinator), IFEU, Wuppertal Institut): Ökologisch optimierter Ausbau der Nutzung erneuerbarer Energien in Deutschland (E-cological optimised implementation of renewable energy in Germany). Commissioned by Federal Ministry for the Environment, Berlin 2004.

EC 2003: Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. Brussels.

EEA 2005a: Greenhouse gas emission trends and projections in Europe 2005, EEA Report No 8/2005

EEA 2005b: Annual European Community greenhouse gas inventory 1990–2003 and inventory report 2005 – Submission to the UNFCCC Secretariat, EEA Technical report No 4/2005.

EEA 2006: European Environment Agency: Erasmia Kitou (DG Environment), Andreas Barkman, Ricardo Fernandez (EEA), Bernd Gugele, Elisabeth Rigler, Manfred Ritter (ETC/ACC): Annual European Community greenhouse gas inventory 1990-2004 and inventory report 2006. Submission to the UNFCCC Secretariat. Final Version – the version including finalised layout will be available soon. EEA Technical report No 6/2006, incl. annexes (for 4. Agriculture and 5. Land-use, land-use change and forestry), Brussels.

Ekström, C., Bröms, G., Eidensten, L., Hammarberg, A., Herbert, P., Kapper, R., Krohn, P., Larsson, S., Rydberg, S., Nyström, O., Olsson F., 2006, Tekniska åtgärder i Sverige för att undvika fraMtonnesida koldioxidutsläpp från produktion och användning av energi - Modellberäkningar av kostnad och potential, Elforsk report 2005:47. Description: MAC-curves for Households, Energy and transport. Only in Swedish.

ESRC 2002: Hanly M., Dargay J. and Goodwin P.: Review if income elasticities and the demand for road traffic. Economic and Social Research Council (ESRC) Transport Studies Unit. London.

EU 2006: The European Climate Change Programme – EU Action against Climate Change.

FFE 2004: Wagner U. and five other authors (FFE): CO_2-Vermeidungskosten im Kraftwerksbereich, bei den erneuerbaren Energien sowie bei nachfrageseitigen Energieeffizienzmaßnahmen (abatement cost in power supply, of renewable energy and of efficiency measures). München 2004.

FiFo et al. 2005: Emissionshandel im Verkehr. Ansätze für einen möglichen Up-Stream Handel im Verkehr. Finanzwissenschaftliches Forschungsinstitut (FiFo) at the University of Cologne et al. UBA Texte 22/05. Köln, Heidelberg, Mannheim, Karlsruhe.

Frasch 2006: Analyse der Transaktionskosten des EU-Emissionshandels in deutschen Unternehmen, Diplomarbeit am Fraunhofer ISI und Universität Lüneburg.

Gerbens S. 1999: Cost-effectiveness of Methane Emission Reduction from Enteric Fermentation of Cattle and Buffalo. Department of Agricultural, Environmental and System Technology (AEST), Agricultural University of Wageningen, Netherlands. Unpublished, 70 p., January 1999.

Graus W., Harmelink M., Hendriks C. 2004: Marginal GHG Abatement curves for agriculture, ECOFYS, Utrecht, the Netherlands.

Hausberger S. 1997: Globale Modellbildung für Emissions- und Verbrauchsszenarien im Verkehrssektor (Global Modelling of Scenarios Concerning Emission and Fuel Consumption in the Transport Sector); Dissertation am Institut für Verbrennungskraftmaschinen und Thermodynamik der TU-Graz; Graz, 1997.

Hausberger S. 2003: Simulation of Real World Vehicle Exhaust Emissions; VKM-THD Mitteilungen; Heft/Volume 82; Verlag der Technischen Universität Graz; ISBN 3-901351-74-4; Graz 2003.

Hausberger S. 2004: Straßenverkehrsemissionen und Emissionen sonstiger mobiler Quellen Österreichs für die Jahre 1990 bis 2003; Erstellt im Auftrag der UmweltbundesaMtonnes GmbH; Graz Dez. 2004.

Hausberger S. et.al. 2002: Update of the Emission Functions for Heavy Duty Vehicles in the Handbook Emission Factors for Road Traffic; Institute for Internal Combustion Engines and Thermodynamics; Graz 2002.

Hausberger S., Rexeis M. 2004: Emission Behavior of Modern Heavy Duty Vehicles in Real World Driving; International Journal of Environment and Pollution; 2004.

Hausberger S., Rodler J., Sturm P., Rexeis M. 2002: Emission factors for heavy-duty vehicles and validation by tunnel measurements , Atmospheric Environment 37 (2003), 5237 – 5245.

Hausberger S., Vuckovic T. 2006a: Fuel Consumption and Emissions of Modern Vehicles; Part "Effects of Admixtures of Biodiesel "; Project carried out under contract with BMLFUW: Report No. FVT-xx/04-6770, Graz 24.2.2006

Hausberger S., Vuckovic Th. 2006b: Vermessung von Verbrauch und Emissionen bei fossilem Diesel und Pflanzenöl am Rollenprüfstand; Bericht Nr. FVT-39/06/ Vuc Em 07/06-6770 vom 1.06.2006, Graz 2006

Hediger W., Hartmann M., Peter S., Lehmann B. 2004: Ökonomische Beurteilung und Monetarisierung der landwirtschaftlichen Leistungen im Klimaschutz, Schriftenreihe ETH Zürich, Institut für Agrarwirtschaft, Zürich, Switzerland, November 2004.

Hendriks C. et al. 1998: Emission Reduction Potential and Costs for Methane and Nitrous Oxide in the EU15, M714, Ecofys, Utrecht.

Holmgren K., Klingspor M., Ribbenhed M., Sternhufvud C. and Thorén M. 2005: Utredning om möjligheterna att minska utsläppen av fossil koldioxid från järn- och stålindustrin, IVL Swedish Environmental Research Institute, B-report B1649. Description: MAC-curve for CO2 for the Swedish iron and steel industry. Only in Swedish. (also English manuscript available for iron-ore based steel industry).

Holmgren, K & Sternhufvud, C., 2006 (in prep). CO2 emission reduction costs for mineral oil refineries in Sweden. (Manuscript submitted to Journal of Cleaner Production). Description: abatement options and costs for mineral oil refineries in Sweden. MAC-curve CO_2 emission reductions.

IEEP 2004: Service contract to carry out economic analysis and business impact assessment of CO_2 emissions reduction measures in the automotive sector, contract nr. B4-3040/2003/366487/MAR/C2, carried out by IEEP, TNO and CAIR on behalf of DG-ENV, 2004.

IFEU 2001: Diaz-Bone H., Hartmann U., Höpfner U., Stronzik M., Weinreich S. and Bergmann H.: Flexible Instrumente der Klimapolitik im Verkehrsbereich. Heidelberg, Mannheim, Stuttgart.

IFEU 2003: Lambrecht U., Höpfner U., Bühler G., Stronzik M., Bergmann H., Jacobs J.-O. and König P.: Flexible Instrumente der Klimapolitik im Verkehrsbereich. Weiterentwicklung und Bewertung von konkreten Ansätzen zur Integration des Verkehrssektors in ein CO_2-Emissionshandelssystem. Heidelberg, Mannheim, Frankfurt, Berlin.

IFEU 2004: Reinhardt G.A.; Gärtner S.O.; Pehnt M.; Quirin M.: CO_2-neutrale Wege zukünftiger Mobilität durch Biokraftstoffe: Eine Bestandsaufnahme (CO_2 neutral paths of future mobility by biofuels). Commissioned by Forschungsvereinigung Verbrennungskraftmaschinen; Heidelberg 2004.

INFRAS 2006a: Cost effectiveness of GHG reductions, Minutes of the kickoff-meeting, 15 May 2006.

INFRAS 2006b: Common framework and methodology, working paper, 2nd revision. Zurich, 25 July 2006.

IPCC 1997: IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, published by IEA/OECD, 1996 revisions.

IPCC 2003: Intergovernmental Panel on Climate Change: Good practice guidance for land use, land use change and forestry, Japan.

IPPR 2006a: Grayling T., Gibbs T. and Castle B.: Tailpipe Trading. How to include road transport in the EU Emissions Trading Scheme. A proposal to the Low Carbon Vehicle Partnership Road Transport Challenge. Institute for Public Policy Research. London.

IPPR 2006b: Gibbs T. and Retallack S.: European Emissions Trading at the Crossroads. Developing proposals for Phase III and beyond. Institute for Public Policy Research. London.

Joosen S. and Blok K. 2001, Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change – Economic Evaluation of Carbon Dioxide Emission Reduction in the Household and Services Sectors in the EU Bottom-up Analysis, Ecofys (The Netherlands) and AEA Technology Environment (UK).

Jungmeier G., Hausberger S., Könighofer K., Wenzel A. 2004: Treibhausgas-Emissionen und Kosten von Transportsystemen mit zukünftigen Biotreibstoffen in Österreich (Greenhouse Gas Emissions and Costs of Transportation Systems with Future Biofuels in Austria); VDI, 2004.

Kauppi P. et al. 2001: Co-ordinating lead authors: Kauppi P. (Finland), Sedjo R. (USA); lead authors: Apps M. (Canada), Cerri C. (Brazil), Fujimori T. (Japan), Janzen H. (Canada), Krankina O. (Russian Federation/USA), Makundi W. (Tanzania/USA), Marland G. (USA), Masera O. (Mexico), Nabuurs G. (Netherlands), Razali W. (Malaysia), Ravindranath N.H. (India); Contributing authors: Keith D. (USA), Kheshgi H. (USA), Liski J. (Finland); Review authors: Calvo E. (Peru), Solberg B. (Norway): Technological and Economic Potential of Options to Enhance, Maintain, and Manage Biological Carbon Reservoirs and Geo-engineering. IPCC Paper.

Keller M. et.al. 2004: Handbuch Emissionsfaktoren des Strassenverkehrs 2.1 Dokumentation; http://www.hbefa.net/; Juli 2004.

Lantin S., Wassmann R., Buendia L., Neue H. 2003: Implementing Mitigation Technologies in Rice Cultivation. International Rice Research Institute.

LEI-DLO 2003: Landbouwcijfers, 2001. Agricultural Economics Research Institute, The Hague. http://www.mnp.nl/mnc/i-en-0013.html

Leifeld J. Bassin S., Fuhrer J. 2003: Carbon stock and sequestration potentials in agricultural soils in Switzerland. Schriftenriehe der FAL 44. Swiss Federal Research Station for Agroecology and Agriculture, FAL Reckenholz, Zürich, Switzerland.

Levington Agriculture 2000: Information from Levington Agriculture, Ipswich, UK.

McCarl and Schneider 2000: U.S. Agriculture's Role in a Greenhouse Gas Emission Mitigation World: An Economic Perspective. Review of Agricultural Economics. 22(1): 134-159.

McCarl and Schneider 2001: Greenhouse gas mitigation in U.S. agriculture and forestry. Science. 294(5551): 2481-2482.

Moss A. 1994: Methane production by ruminants – Literature review of I. Dietary manipulation to reduce methane production and II. Laboratory procedures for estimating methane potential of diets. Nutrition Abstracts and Reviews (Series B) 64 (12): 186-806.

PRIMES (2005) is a partial equilibrium model for the European Union energy system developed and maintained at the National Technical University of Athens

PwC 2002: Hohenstein C., Pelchen A. and Wieler B.: Zertifikatehandel im Verkehrsbereich als Instrument zur CO_2-Reduzierung unter Berücksichtigung von Interdependenzen mit anderen Lenkungsinstrumenten und unter Gewährleistung der Kompatibilität zur EU-Gesetzgebung. PricewaterhouseCoopers (PwC). Berlin.

Reimersma, I., Vermuelen, R., Gense, R., Smokers, R., N_2O emissions of LD and HD vehicles, TNO Automotive, The Netherlands

Särnholm, E., 2005, Åtgärdskostnader för minskning av koldioxidutsläpp vid svenska kraftvärme- och värmeanläggningar, IVL Swedish Environmental Research Institute, B-report B1650. Description: MAC-curve for CO_2 for the Swedish energy sector. Only in Swedish.

Schmerler J. and Basten M. 1999: Cost Benefit Analysis of Introducing Site-Specfic Management on a Commercial Farm, Precision Agriculture '99, Part 2, Edited by John V Stafford, Sheffield Academic Press, 1999.

SEPA 2006: Dealing with Transport Emissions. An emission trading system for the transport sector, a viable solution? Swedish Environmental Protection Agency (SEPA). Stockholm.

Stripple, H., Sternhufvud, C. and Skårman, T., 2005, Utredning om möjligheterna att minska utsläppen av fossil koldioxid från mineralindustrin, IVL Swedish Environmental Research Institute, B-report B1651. Description: MAC-curve for CO2 at the Swedish cement industry. Only in Swedish.

TNO 2004a: R.J. Vermeulen, N.L.J. Gense, R.T.M. Smokers, The design of a measurement procedure for the determination of the additional fuel consumption of passenger cars due to the use of mobile air conditioning equipment, carried out by TNO Automotive on behalf of DG-ENV (contract nr. B4-3040/2003/367487/MAR/C1), 2004.

TNO 2004b: Study contract on measuring and preparing reduction measures for CO2 emissions from N_1 vehicles, study for DG Environment carried out by TNO, IEEP, LAT/AUTh, 2004.

TNO 2006: Review and analysis of the reduction potential and costs of technological and other measures to reduce CO2-emissions from passenger cars, Richard Smokers et al., by TNO, IEEP en LAT on behalf of the European Commission DG-ENTR (contract SI2.408212), TNO report 06.OR.PT.040.2/RSM, October 2006

TREMOVE: http://www.tremove.org/

Van Nevel C. and Demeyer D. 1992: Influence of antibiotics and a deaminase inhibitor on volatile fatty acids and methane production from detergent washed hay and soluble starch by rumen microbes in vitro. Animal Feed Science and Technology 37: 21-31.

VIEWSL 200: Varela M. et al: Life cycle economic and environmental analysis of biofuels in Europe. Commissioned by the EU Commission; Madrid 2006.

Weiske A. 2005: Survey of technical and management-based mitigation measures in agriculture. MEACAP Impact of Environmental Agreements on the Common Agricultural Policy (CAP), Document number: MEACAP WP3 D7a, June 2005.

Worrell E. 1994: Potentials for Improved Use of Industrial Energy and Materials, Utrecht University, Faculteit Scheikunde, Netherlands.

Zeeman G. 1991: Mesophilic and psychrophilic digestion of liquid manure, PHD Thesis, Department of Environmental Technology, Agricultural University of Wageningen, Wageningen, The Netherlands.

Zeeman G. 1994: Methane production/emission in storages for animal manure, Fertiliser Research 37(3), 207-211.

ZEW 2006: Service contract in Support of the Impact Assessment of Various Policy Scenarios to Reduce CO2 Emissions from Passenger Cars, Sabine Jokisch et al. by ZEW and B&D Forecast on behalf of the European Commission DG-ENV (contract no. 070501/2004/392571/MAR/C1), October 2006.

ANNEXES

- Annex to chapter 3: Abstracts of reviewed literature
- Annex to chapter 4.2: Manufacturing industry, household and service sectors
  - Details regarding sectoral MACs
  - Details regarding Scenarios
- Annex to chapter 4.3: Agricultural and forestry sector
  - Sectoral literature sources
  - Description of policies and measures ot the agricultural and forestry sector
    - A) Measures described by Blok
    - B) Other measures (not described by Blok)
- Annex to chapter 5.2: Heavy Duty Vehicles: Methodology and models for HDV assessment
- Annex to chapter 6.3: All measures sorted by marginal abatement costs

ANNEX TO CHAPTER 3: GENERAL, CROSS SECTORAL STUDIES: ABSTRACTS OF REVIEWED LITERATURE

No.	Reference	Page	Preliminary abstracted information
	General comment on IPCC reports available: All IPCC WG3 reports are secondary info: compilations of a wider range of primary studies. Geographical: generally World wide with regional differentiation (developed Countries-OECD+EIT, and DCs by Region); EU: since studies date mostly to pre 2000, they often consider EU with less than 15 / 23 or even 15 member states (EU6, EU11) GHGs: varies between studies considered Elaborate -Scenario Analyses: Differing Baseline and implicit mitigation scenarios (long range, by decade 1990 up to 2100, differing depending on study consid-ered) with wide range of framework assumptions: (population, economy, equity, environment, technology, and globalisation. Quantitative Data primarily 1990 to 1995 and 2000; 4 scenario “families”, were developed by the IPCC and published as the Special Report on Emissions Scenarios (SRES). (diagrams of scenario families see P. 25 of 58)		
1	IPCC_WG3_Mitigation Ch4_GHG_ReductionPotentials WG3: Chapter 4: **Technological and Economic Potential of Options to Enhance, Maintain, and Manage Biological Carbon Reservoirs and Geoengineering** PEKKA KAUPPI (FINLAND), ROGER SEDJO (USA) Lead Authors: Michael Apps (Canada), Carlos Cerri (Brazil), Takao Fujimori (Japan), Henry Janzen (Canada), Olga Krankina (Russian deration/USA), Willy Makundi (Tanzania/USA), Gregg Marland (SA), Omar Masera (Mexico), Gert-Jan Nabuurs (Netherlands), Wan Razali (Malaysia), N.H. Ravindranath (India	44	Sectors considered: Land use and – management in Agriculture and forestry (but only as Carbon reservoirs, not as emittors of GHG, such as NH4 in agriculture etc) Geographical focus is on Asian, African and south American countries, mostly developing (non- annex B) Figure 4.9. compares MAC curves for forest management in three world regions with other policy areas such as, renewable energies, fuel switch energy efficiency. (USD /tC vs Mio Tons of C reduced) MAC oriented data only for specific cases, such as a measure or sector in a specific country or region, depending on studies available. (years 190 to 2000)
2	IPCC_WG3 Mitigation_Ch3_GHG_ReductionPotentials Technological and Economic Potential of Greenhouse Gas Emissions Reduction **Co-ordinating Lead Authors**: WILLIAM R. MOOMAW (USA), JOSE ROBERTO MOREIRA (BRAZIL) **Lead Authors**: Kornelis Blok (Netherlands), David L. Greene (USA), Ken Gregory (UK), Thomas Jaszay (Hungary), Takao Kashiwagi (Japan), Mark Levine (USA), Mack McFarland (USA), N. Siva Prasad (India), Lynn Price (USA), Hans-Holger Rogner (Germany), Ralph Sims (New Zealand), Fengqi Zhou (China), Peter Zhou (Botswana)	134	Sectors: buildings, Transport+mobility, Manufacturing, Energy supply, Waste, Agri+Energy, Cropping. Statistical data for CO2 and GHG emissions, and energy consumption up to about 1998, for each of 6 world-regions, Estimate: (Page 260) there is technological potential for reductions of between 1900 and 2600 Mtonnes Ceq/a in 2010 and 3,600 to 5,050MtonnesCeq/a in 2020. Half of these reductions are achievable at net negative costs and most of the remainder is available at a cost of less than USD100tCeq/a. The continued development and adoption of a wide range of greenhouse gas mitigation technologies and practices will result not only in a large technical and economic potential for reducing greenhouse gas emissions but will also provide continued means for pursuing sustainable development goals.

3	IPCC_WG3_Mitigation Ch7_Costing_Methodologies	41	This is a methodological study; no quantitative results from empirical or theoretical modelling studies. Useful for information on terminology and methods of modelling and cost-and benefit – calculation
4	IPCC_WG3_Mitigation Ch8_RegionalCosts	62	This doc shows the more useful MAC oriented infos of the IPCC chapters of WG3. Fig 8.2. p 508 shows cross sectoral MAC Curves for various regions, also EU (15?), for different Modelling (partial equilib model-Studies, all done between 1997 and 2000. Net costs are calculated, considering secondary and primary benefits as well, according to Ch 8, and refer to domestic policies, but no sectoral MACs are shown. The range of reduction potential for EU, at MACs up to 50 $/t Cist shown as about 25-40%. For Macs up to 100 and 200 $/tC, the reduction s range between (35-55%; and 50-70% respectively) In section 8.2. MACs are estimated on the basis of the impact of a carbon tax. Curves for carbon tax ($/tC) vs. % Reduction relative to the baseline are shown for various studies, and for regions: USA, OECD-Europe, Japan, and CANZ (other OECD countries) Here, the Macs are much higher than those cited above (OECD-europe: at 200$/tC: 8-25% reduction))
5	IPCC_WG3_Mitigation Ch9_SectorCosts Sector Costs and Ancillary Benefits of Mitigation Co-ordinating Lead Authors: Terry Barker (UK), Leena Srivastava (India)	40	Sectors discussed are: Energy production, Agriculture and forestry, construction, transport, services, and households Costs discussed are top down results of socio economic cost per sector, rather than MACs computed with bottom up analysis per measure Secondary (ancillary) benefits are discussed qualitatively
6	IPCC_WG3_Mitigation Summary_PM **Summary for policymakers climate change mitigation 2001: A Report of Working Group III of the Intergovernmental Panel on Climate Change** This summary, approved in detail at the Sixth Session of IPCC Working Group III (Accra, Ghana • 28 February - 3 March 2001), represents the formally agreed statement of the IPCC concerning climate change mitigation. **Based on a draft prepared by:** Tariq Banuri, Terry Barker, Igor Bashmakov, Kornelis Blok, Daniel Bouille, Renate Christ, Ogunlade Davidson, Jae Edmonds, Ken Gregory, Michael Grubb, Kirsten Halsnaes, Tom Heller, Jean-Charles Hourcade, Catrinus Jepma, Pekka Kauppi, Anil Markandya, Bert Metz, William Moomaw, Jose Roberto Moreira, Tsuneyuki Morita, Nebojsa Nakicenovic, Lynn Price, Richard Richels, John Robinson, Hans Holger Rogner, Jayant Sathaye, Roger Sedjo, Priyaradshi Shukla, Leena Srivastava, Rob Swart, Ferenc Toth, John Weyant	14	Gives an overview of the work and results of WG3, for policy makers No specific quantitative data Scenarios are shown (Baseline and Mitigation) 50% of the reduction potentials shown are claimed to be realsisable at negative net cost, and the other half at MAC of < 100 USD/tC. Discount rates between 5 and 12% are used in the different studies evaluated. Reduction options are discussed for each of sectors

7	IPCC_WG3_Mitigation Technical_Summary TECHNICAL SUMMARY CLIMATE CHANGE 2001: MITIGATION A Report of Working Group III of the Intergovernmental Panel on Climate Change This summary was accepted but not approved in detail at the Sixth Session of IPCC Working Group III (Accra, Ghana • 28 February – 3 March 2001). “Acceptance” of IPCC reports at a session of the Working Group or Panel signifies that the material has not been subject to line-by-line discussion and agreement, but nevertheless presents a comprehensive, objective, and balanced view of the subject matter. Lead Authors: Tariq Banuri (Pakistan), Terry Barker (UK), Igor Bashmakov (Russian Federation), Kornelis Blok (Netherlands), John Christensen (Denmark), Ogunlade Davidson (Sierra Leone), Michael Grubb (UK), Kirsten Halsnaes (Denmark), Catrinus Jepma (Netherlands), Eberhard Jochem (Germany) etc.	58	Reviews results, including wide spectrum of baseline and mitigation scenarios some summary of MAC results (P 28 ff.) methodologies for Costing, MAC summaries; P. 28ff, by 2010: Industrial sector: MAC= neg to 300 USD/tC; Residential Buildings sector: OECD+EIT: 325 Miot C/a at neg.cost to 250USD/tC, and 125Miot in DCs for neg to 50 USD/tC. Commercial buildings: 185 Mot in OECD+EIT at -400 to +250 USD7TC; and 80MiotC in DC’s for -400 USD/tC to 0 USD Transport sector: MACs between -220 to +300 USD/tC, Agri sector: MACs between -100 up to 300 USD/tC Materials management (recycling etc.) MACs are neg to 100 USD/tC. Energy pro. Sector: MAC: -100 to +200 USD/tC
8	EEA_2005 GHG_trends_projections EEA Report No 8/2005 Greenhouse gas emission trends and projections in Europe 2005 Luxembourg: Office for Official Publications of the European Communities, 2005 ISBN 92-9167-780-9 , ISSN 1725-9177, © EEA Copenhagen 2005	46 plus 8 apendices (Tables)	Shows actual GHG emission development 1990 to 2003, and projections to 2010 for the (EU 15, 23 25) and its Member States, and acceding and candidate countries and EEA countries GHG emission targets per nation are shown according to EU burdensharing scheme Actual GHG emissions in 2003 are given by country Projection for EU 23 in 2010: 95% of 1990 value with existing measures, and 91% with additional measures (i.e. 1% overdelivered the Kyoto target) Same information per country and per sector (combined disaggregation not shown) Linkages between CCPM and national policies and measures No cost data available.

9	COHERENCE_2001 Econ_eval_of_quant_objectives Economic Evaluation of Qunatitative Objectives for Climate Change COHERENCE, Belgium With the support of ECOFYS, the Netherlands National University of Athens (NTUA), Greece ECOSIM, UK		The overall objective of the study was to conduct an economic evaluation of EU's Kyoto target. More specifically, the study aimed at: 1) identifying the least-cost packages of specific policies and measures for meeting the Community's quantitative reduction for greenhouse gases under the Kyoto Protocol. This evaluation included an analysis of the relative role of carbon dioxide, methane and nitrous oxide emissions, and of the different sectors of the economy (i.e. power production, industry, tertiary-domestic, transport, waste sector and agriculture). It combined two methodologies for the assessment of potentials and costs of reduction: ECOFYS cost curve methodology for methane and nitrous oxide, and the PRIMES partial equilibrium approach for CO_2. 2) analysing the costs and emission reductions of an emission trading system towards meeting the goals in a cost-effective way. In particular, the analysis included an assessment of the costs of a ceiling on CO_2 trading. The study results came from the POLES model (a sectoral model of the world energy system to 2030). The study provides useful information for the determination of sectoral targets as well as on the least-cost allocation of reduction effort between the different greenhouse gases.

0	JRC_2005 Analysis of Post-2012 Climate Policy Scenarios with Limited Participation_eur21758en P. Russ, J. C. Ciscar, and L. Szabó European Commission Joint Research Centre (DG JRC) Institute for Prospective Technological Studies This document presents part of the modelling work con-ducted by DG JRC/IPTS as a contribution to the DG ENV Communication on post-2012 climate policy analy-sis. June 2005		DG JRC/IPTS has carried out an analysis of additional climate policy scenarios, using the POLES and GEM-E3 models of the Criqui et al. (2003) report. These are large-scale numerical models of the global energy and economic systems, respectively. This document presents the analysis of those scenarios. The two models have complementary characteristics. The POLES model is a partial equilibrium model of the global energy system, with a technologically detailed characterisation of the energy transformation sectors and energy intensive industries. GEM-E3 is a world multi-region, multi-sectoral computable general equilibrium model, suitable for the analysis of the interactions between all the sectors in the economy. The analyses with the POLES and GEM-E3 models show that the costs of abatement policies, both in marginal terms and total terms, can be significantly reduced if emissions trading and project based mechanisms are used.
11	EC_ENV_2003: GHG_Red_Pathways_upto_2025 GREENHOUSE GAS REDUCTION PATHWAYS IN THE UNFCCC PROCESS UP TO 2025 – POLICYMAKERS SUMMARY Study for the DG Environment by CNRS/LEPII-EPE (France) – RIVM/MNP (Netherlands) – ICCS-NTUA (Greece) – CES-KUL (Belgium) October 2003		The “Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025” report, explores possible climate regimes and greenhouse gas (GHG) reduction targets up to the 2025 time horizon, given certain greenhouse gas stabilisation targets. The economic implications of various countries’ full or increasing participation in international climate policy architectures is analysed using two partial equilibrium models (POLES and IMAGE-TIMER) and one general equilibrium model (GEM-E3). Two constrained global emission profiles have been developed. They correspond to stabi-lising the total greenhouse gas concentration at levels of 550 and 650 ppmv in CO_2 equivalent, for the set of six greenhouse gases covered by the Kyoto Protocol. Cost and benefits of the scenarios are analysed. No explicit sectoral MACs are shown.
12	EC_2005 Winning-the-battle_staff_work_paper COMMISSION STAFF WORKING PAPER Winning the battle against global climate change Background paper		As a basis for the consideration of medium and longer term emission reduction strategies, the European Council asked the Commission to analyse the costs and the benefits of post-2012 actions to mitigate climate change, taking into account both their environmental and economic consequences. The Commission’s Communication on Action on Climate Change Post-2012, “Winning the Battle against Global Climate Change” (European Commission, 2005), was its response to that request, and it drew upon a number of quantitative studies. The study analyses the costs of inaction and the benefits of climate mitigation by a model based approach. The potential magnitude of these costs is very high. On the other hand the cost of mitigation and the effects of flexible mechanisms are analysed based on a model approach as well (POLES model). No explicit MACs are shown in the paper.

13	EC_2006 Eu_climate_change_program (brochure) ECCP from 2005 onwards:	21	Policy oriented EU15 program, worked out by 11 working groups. Orientation is along 8 policy areas, with a number of EU guideline oriented policies in each area. Emission projections for EU 15 and 23/25 are included as well. For many measures estimates for reduction potential (2010) are given, but no cost information. Information on status of implementation. Policy areas are: 1. Cross cutting, 3 policy elements: (e.g. ETS in EU, CDM), 2. Energy supply, 5 policy elements total red potential. 3. Energy demand, 11 policy elements, 4. Transport, 7 policy elements 5. Industry incl waste management, 4 policy elements 6. Agriculture + forestry; 3 policy elements 7. R+D, 2 policy elements 8. 1 policy element
14	AEA_SEI_2005 The Impacts and Costs of Climate Change_final_report2 The Impacts and Costs of Climate Change Final Report September 2005 Paul Watkiss, Tom Downing, Claire Handley, Ruth Butterfield AEA Technology Environment Stockholm Environment Institute, Oxford Commissioned by European Commission DG Environ-ment Prepared as task 1 of the project ‘Modelling support for Future Actions – Benefits and Cost of Climate Change Policies and Measures’. ENV.C.2/2004/0088.		This paper is prepared as task 1 of the project ‘Modelling support for Future Actions – Benefits and Cost of Climate Change Policies and Measures’, ENV.C.2/2004/0088, led by K.U.Leuven, Katholieke Universiteit Leuven. The paper provides a rapid review and analysis of the impacts and economic costs from climate change. The objective is to provide estimates of the benefits of climate change policy, i.e. from avoided impacts, for support to the Commission in considering the bene-fits and costs of mitigation efforts, and to support DG Environment in its report to the Spring Council 2005 and in future international negotiations on climate change. The study has briefly considered adaptation. Reviews of climate change adaptation work have shown that climate change costing studies often pay little attention to adaptation costs and further research would increase the reliability of adaptation cost estimates.
15	AEA_2004 Costs and environmental effectiveness of options for reducing air pollution_SCI AEAT/ED48256/Final Report Issue 2 Costs and environmental effectiveness of options for reducing air pollution from small-scale combustion installations Final Report for European Commission DG Environment November 2004		This study was undertaken to: - Assess the significance of emissions of different pollutants from Small combustion installations (SCIs) - Characterise the type of SCIs, and associated fuels used, across Europe - Identify the range of different options for reducing emissions - Propose a range of feasible and cost-effective measures for consideration in the - Thematic Strategy A large number of policy options were identified, most of which have been assessed in this study, while a limited number were rejected for reasons including limitation of applica-tion across Europe. Cost of different measures are analysed.

ANNEX TO CHAPTER 4.2: MANUFACTURING INDUSTRY, HOUSEHOLD AND SERVICE SECTORS

	All measure originate from the sector report of Blok (2001a)	Data of orig. source		Assessment					
		MAC (Blok et al. 2001a)	GHG Red.[98]	Cate-gory[99]	CF[100]	MAC[101]	GHG Red.[102]	GHG Red.[103]	GHG Red.[104]
		€1990/ton	Mtonnes CO_{2eq}/a			€2003/ton	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a
1	Energy efficient TV and video equipment	-194	1	-	1	-235	0.6	0.4	0.4
2	Very energy efficient refrigerators and freezers	-187	0.5	-	1	-227	0.2	0.0	0.0
3	Efficient lightning: Best Practice (partly implemented)	-181	1	3	1	-219	0.0	0.0	0.0
4	Efficient lightning: Best Practice (fully implemented)	-178	2	3	1	-216	0.7	0.5	0.5
5	Miscellaneous options (cheap tranche)	-165	11	-	1	-200	1.3	0.0	0.0
6	Miscellaneous options (moderate costs tranche)	-156	11	-	1	-189	3.9	2.6	0.0
7	Efficient refrigerators and freezers: Best Practice	-57	3	-	1	-69	1.8	1.1	0.0
8	Retrofit houses: wall insulation	-42	28	-	1	-51	15.0	13.3	0.0
9	Retrofit houses: roof insulation	-29	26	3	1	-35	12.4	9.3	0.0
10	New energy efficient residential houses: (Best practice)	-11	12	-	1	-13	3.6	2.1	0.0
11	Domestic refrigeration: hydrocarbons	3	1	-	1	4	0.6	0.4	0.0

---

[98] Emission reduction potential in EU15 with the FTRL (2010) as baseline (Blok, 2001a).

[99] The category is valid for the MAC in the case of this sector. Very few data have been possible to validate due to lack of information.

[100] This correction factor is 1 for all measures due to lack of information. Other correction factors are presented in table Table .

[101] The MAC-data are updated due to the deflation that has occurred between 1990 and 2003 (21.2%).

[102] Emission reduction potential for PAM0+ in EU25 with the scenario 0 (2010) as baseline.

[103] Emission reduction potential for PAM1+ in EU25 with the scenario 1 (2010) as baseline.

[104] Emission reduction potential for PAM1+ in EU25 with the scenario 1 (2010) as baseline. Only measures reducing CO_2 emissions in the EU ETS is included.

All measure originate from the sector report of Blok (2001a)		Data of orig. source		Assessment					
		MAC (Blok et al. 2001a)	GHG Red.[98]	Category[99]	CF[100]	MAC[101]	GHG Red.[102]	GHG Red.[103]	GHG Red.[104]
		€1990/ton	Mtonnes CO_{2eq}/a			€2003/ton	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a
12	Efficient washing machines, clothes dryers, dish washers: Best Practice	7	1	-	1	8	0.5	0.2	0.2
13	Retrofit houses: (highly) insulated windows	10	49	3	1	12	8.7	5.8	0.0
14	Advanced heating systems: condensing boilers	50	15	-	1	61	4.5	2.7	0.0
15	Geothermal heat production	58	0.2	-	1	70	0.0	0.0	0.0
16	New very energy efficient residential houses: Zero Energy	71	3	-	1	86	0.7	0.5	0.0
17	Solar thermal	272	8	-	1	330	2.9	1.9	0.0
18	Advanced heating systems: heat pumps	432	16	-	1	524	5.7	3.8	3.8
	Total		188.7				63.0	44.6	4.9

Table 73 Measures to reduce GHG in the households sector. The correction factors used to recalculate the emission reductions and MAC are found Table .

All measure originate from the sector report of Blok (2001a)		**Correction of reduction potential**[105]					**Correction of MAC-data**
		$CF_{EU15-EU25}$ **EU25/EU15**	CF_{time}	$CF_{scenario\ 0}$	$CF_{scenario\ 1}$	CF_{EU-ETS}	$CF_{inflation}$
			(% left for reduction potential)				**€$_{2003}$ / €$_{1990}$**
1	Energy efficient TV and video equipment	1.19	100%	50%	30%	100%	1.212
2	Very energy efficient refrigerators and freezers	1.19	100%	30%	0%	100%	1.212
3	Efficient lightning: Best Practice (partly implemented)	1.19	100%	0%	0%	100%	1.212
4	Efficient lightning: Best Practice (fully implemented)	1.19	100%	30%	20%	100%	1.212
5	Miscellaneous options (cheap tranche)	1.19	100%	10%	0%	100%	1.212
6	Miscellaneous options (moderate costs tranche)	1.19	100%	30%	20%	0%	1.212
7	Efficient refrigerators and freezers: Best Practice	1.19	100%	50%	30%	0%	1.212
8	Retrofit houses: wall insulation	1.19	80%	65%	60%	0%	1.212
9	Retrofit houses: roof insulation	1.19	80%	60%	50%	0%	1.212
10	New energy efficient residential houses: (Best practice)	1.19	60%	65%	55%	0%	1.212
11	Domestic refrigeration: hydrocarbons	1.19	100%	50%	30%	0%	1.212
12	Efficient washing machines, clothes dryers, dish washers: Best Practice	1.19	70%	70%	50%	100%	1.212
13	Retrofit houses: (highly) insulated windows	1.19	30%	85%	80%	0%	1.212
14	Advanced heating systems: condensing boilers	1.19	40%	85%	75%	0%	1.212
15	Geothermal heat production	1.19	25%	90%	80%	0%	1.212

---

[105] See chapter 4 for the definitions of the different CF.

All measure originate from the sector report of Blok (2001a)		**Correction of reduction potential**[105]					**Correction of MAC-data**
		$CF_{EU15\text{-}EU25}$	CF_{time}	$CF_{scenario\ 0}$	$CF_{scenario\ 1}$	$CF_{EU\text{-}ETS}$	$CF_{inflation}$
		EU25/EU15	**(% left for reduction potential)**				**$€_{2003}$ / $€_{1990}$**
16	New very energy efficient residential houses: Zero Energy	1.19	25%	95%	90%	0%	1.212
17	Solar thermal	1.19	40%	90%	80%	0%	1.212
18	Advanced heating systems: heat pumps	1.19	40%	90%	80%	100%	1.212

Table 74 The correction factors used for the assessment of the measures in the households sector.

	All measure originate from the sector report of Blok (2001a)	Data of orig. source		Assessment					
		MAC (Blok, 2001a)	GHG Red.[106]	Category[107]	CF[108]	MAC[109]	GHG Red.[110]	GHG Red.[111]	GHG Red.[112]
		€1990/ton	Mtonnes CO_{2eq}/a			€2003/ton	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a
1	Efficient office equipment: Best Practice	-178	3	3	1	-216	0.0	0.0	0.0
2	Building Energy Management Systems (BEMS): electricity	-178	3	3	1	-216	0.0	0.0	0.0
3	Efficient space coling equipment	-172	1	-	1	-208	0.1	0.1	0.1
4	Efficient lighting: Best Practice level 1	-159	2	3	1	-193	0.5	0.2	0.2
5	Very efficient lighting: Best Practice level 2	-144	1	3	1	-175	0.2	0.2	0.2
6	Building Energy Management Systems (BEMS): space heating and cooling	-129	42	-	1	-156	10.2	7.7	0.0
7	Retrofit services buildings: wall insulation	-26	14	-	1	-32	3.4	2.6	0.0
8	Retrofit services buildings: roof insulation	-8	13	-	1	-10	3.2	2.4	0.0
9	Retrofit services buildings: (highly) insulated windows	35	31	3	1	42	9.5	5.7	0.0
10	Stationary air conditioning DX (distributed technology): leak reduction	37	1	-	1	45	0.2	0.2	0.0
11	Stationary air conditioning chiller: HC and NH3	42	1	-f	1	51	0.2	0.2	0.0
12	Commercial refrigeration: leakage reduction	49	2	-	1	59	0.5	0.4	0.0
13	New energy efficient services buildings: Energy efficiency level 1	146	9	-	1	177	3.3	2.2	0.0
14	New very energy efficient services buildings: Energy efficiency level 2	312	3	-	1	378	2.2	1.5	0.0

---

[106] Emission reduction potential in EU15 with the FTRL (2010) as baseline (Blok et al. 2001a).

[107] The category is valid for the MAC in the case of this sector. Very few data have been possible to validate due to lack of information.

[108] This correction factor is 1 for all measures due to lack of information. Other correction factors are presented in table Table .

[109] The MAC-data are updated due to the deflation that has occurred between 1990 and 2003 (21.2%).

[110] Emission reduction potential for PAM0+ in EU25 with the scenario 0 (2010) as baseline.

[111] Emission reduction potential for PAM1+ in EU25 with the scenario 1 (2010) as baseline.

[112] Emission reduction potential in EU25 with the scenario 1 (2010) as baseline. Only measures reducing CO_2 emissions in the EU ETS is included.

All measure originate from the sector report of Blok (2001a)	Data of orig. source		Assessment					
	MAC (Blok, 2001a)	**GHG Red.**[106]	**Category**[107]	**CF**[108]	**MAC**[109]	**GHG Red.**[110]	**GHG Red.**[111]	**GHG Red.**[112]
	€1990/ton	**Mtonnes CO_{2eq}/a**			**€2003/ton**	**Mtonnes CO_{2eq}/a**	**Mtonnes CO_{2eq}/a**	**Mtonnes CO_{2eq}/a**
Total		126				33.6	23.2	0.5

Table 75 Measures to reduce GHG in the services sector. The correction factors used to recalculate the emission reductions and MAC are found in Table .

All measure originate from the sector report of Blok (2001a)		Correction of reduction potential[113]					Correction of MAC-data
		$CF_{EU15-EU25}$	CF_{time}	$CF_{scenario\ 0}$	$CF_{scenario\ 1}$	CF_{EU-ETS}	$CF_{inflation}$
		EU25/EU15	(% left for reduction potential)				€2003/€1990
1	Efficient office equipment: Best Practice	1.22	100%	0%	0%	100%	1.212
2	Building Energy Management Systems (BEMS): electricity	1.22	100%	0%	0%	100%	1.212
3	Efficient space coling equipment	1.22	100%	10%	10%	100%	1.212
4	Efficient lighting: Best Practice level 1	1.22	100%	20%	10%	100%	1.212
5	Very efficient lighting: Best Practice level 2	1.22	100%	20%	15%	100%	1.212
6	Building Energy Management Systems (BEMS): space heating and cooling	1.22	100%	20%	15%	0%	1.212
7	Retrofit services buildings: wall insulation	1.22	100%	20%	15%	0%	1.212
8	Retrofit services buildings: roof insulation	1.22	100%	20%	15%	0%	1.212
9	Retrofit services buildings: (highly) insulated windows	1.22	100%	25%	15%	0%	1.212
10	Stationary air conditioning DX (distributed technology): leak reduction	1.22	100%	20%	15%	0%	1.212
11	Stationary air conditioning chiller: HC and NH3	1.22	100%	20%	15%	0%	1.212
12	Commercial refrigeration: leakage reduction	1.22	100%	20%	15%	0%	1.212
13	New energy efficient services buildings: Energy efficiency level 1	1.22	100%	30%	20%	0%	1.212
14	New very energy efficient services buildings: Energy efficiency level 2	1.22	100%	60%	40%	0%	1.212

Table 76 The correction factors used for the assessment of the measures in the services sector.

---

[113] See chapter 4 for the definitions of the different CF.

	All measure originate from the sector report of Blok (2001a)	Data of orig. source		Assessment					
		MAC (Blok, 2001a)	GHG Red.[114]	Cate-gory*2	CF*3	MAC[115]	GHG Red.[116]	GHG Red.[117]	GHG Red.[118]
		€1990/ton	Mtonnes CO_{2eq}/a			€$_{2003}$/ton	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a	Mtonnes CO_{2eq}/a
1	Application of continuous casting	-230	1	-	1	-279	0.0	0.0	0.0
2	Improved process control	-76	2	-	1	-92	0.0	0.0	0.0
3	Miscellaneous	-75	0.5	-	1	-91	0.0	0.0	0.0
4	Debottlenecking	-75	6	-	1	-91	0.0	0.0	0.0
5	Miscellaneous I (Low cost tranche)	-67	2	-	1	-81	0.0	0.0	0.0
6	Micellaneous II (High cost tranche)	-58	2	-	1	-70	0.0	0.0	0.0
7	Process integration, e.g. by applying pinch technology	-56	0.3	-	1	-68	0.0	0.0	0.0
8	Ceramics - new capacity	-54	3	-	1	-65	0.0	0.0	0.0
9	Miscellaneous I (Low cost tranche)	-53	54	-	1	-64	6.8	3.4	3.4
10	Electricity savings	-50	0.2	-	1	-61	0.1	0.0	0.0
11	Fractionation - various options	-50	0.3	-	1	-61	0.1	0.1	0.1
12	Miscellaneous I (Low cost tranche)	-49	38	-	1	-59	7.1	4.8	4.8
13	Food, beverages and tobacco - micellaneuous I (Low cost tranche)	-49	20	-	1	-59	3.8	2.5	2.5
14	Miscellaneous	-47	11	-	1	-57	2.1	1.4	1.4
15	Glass - new capacity	-45	0.4	-	1	-55	0.1	0.1	0.1
16	Miscelleneous - building materials	-44	6	-	1	-53	1.1	0.8	0.8
17	Raising cullet percentage in raw material	-44	1	-	1	-53	0.2	0.1	0.1
18	Paper - New capacity	-43	8	-	1	-52	1.5	1.0	1.0
19	Electricity savings	-39	1	-	1	-47	0.2	0.1	0.1
20	Cement - new capacity	-38	5	-	1	-46	0.9	0.6	0.6
21	Process integration, e.g. by applying pinch technology	-37	0.1	-	1	-45	0.0	0.0	0.0

---

[114] Emission reduction potential in EU15 with the FTRL (2010) as baseline (Blok, 2001a).

[115] The MAC-data are updated due to the deflation that has occurred between 1990 and 2003 (21.2%).

[116] Emission reduction potential in EU25 with the scenario 0 (2010) as baseline.

[117] Emission reduction potential in EU25 with the scenario 1 (2010) as baseline.

[118] Emission reduction potential in EU25 with the scenario 1 (2010) as baseline. Only measures reducing CO_2 emissions in the EU ETS is included.

	All measure originate from the sector report of Blok (2001a)	Data of orig. source MAC (Blok, 2001a) €1990/ton	 GHG Red.[114] Mtonnes CO_{2eq}/a	Assessment Cate-gory*2	 CF*3	 MAC[115] $€_{2003}$/ton	 GHG Red.[116] Mtonnes CO_{2eq}/a	 GHG Red.[117] Mtonnes CO_{2eq}/a	 GHG Red.[118] Mtonnes CO_{2eq}/a
22	Food, beverages and tobacco - micellaneuous II (High cost tranche)	-35	28	-	1	-42	5.3	3.5	3.5
23	Miscellaneous I (Low cost tranche)	-35	14	-	1	-42	2.6	1.8	1.8
24	Reduce clinker content of cement	-34	1	-	1	-41	0.2	0.1	0.1
25	Improving wet process kilns	-34	2	-	1	-41	0.4	0.3	0.3
26	Use of waste derived fuels	-33	3	-	1	-40	0.6	0.4	0.4
27	Optimisation of heat recovery of clinker cooler	-31	1	-	1	-38	0.2	0.1	0.1
28	Pulverised coal injection up to 30% in the blast furnace (primary steel)	-30	1	-	1	-36	0.5	0.4	0.4
29	Efficient CO_2 separation (e.g. by using membranes)	-29	0.03	-	1	-35	0.0	0.0	0.0
30	Improved drying, e.g. condensing belt drying	-28	1	-	1	-34	0.5	0.4	0.4
31	Miscellaneous II (High cost tranche)	-26	11	-	1	-32	5.5	4.1	4.1
32	Cracking furnace - variuous options	-23	0.2	-	1	-28	0.1	0.1	0.1
33	Miscellaneous II (High cost tranche)	-22	54	-	1	-27	20.3	13.5	13.5
34	Miscellaneous	-12	4	-	1	-15	1.5	1.0	1.0
35	Other non-ferro metals - miscellaneuous	-11	10	-	1	-13	3.8	2.5	2.5
36	Batch and cullet preheating	-11	1	-	1	-13	0.4	0.3	0.3
37	Miscellaneous II (High cost ranche)	-11	33	-	1	-13	12.4	8.3	8.3
38	Application of multi-stage preheaters and pre-calciners	-10	0.2	-	1	-12	0.1	0.1	0.1
39	Pressing to higher consistency, e.g. by extended nip press (paper making)	-9	5	-	1	-11	1.9	1.3	1.3
40	Industrial refrigeration: hydrocarbons and NH_3	-9	1	-	1	-11	0.4	0.3	0.0
41	Application of efficient evaporation processes (dairy)	-8	1	-	1	-10	0.4	0.3	0.3

All measure originate from the sector report of Blok (2001a)		Data of orig. source		Assessment					
		MAC (Blok, 2001a)	GHG Red.[114]	Cate-gory*2	CF*3	MAC[115]	GHG Red.[116]	GHG Red.[117]	GHG Red.[118]
		€1990/ton	Mtonnes CO$_{2eq}$/a			€$_{2003}$/ton	Mtonnes CO$_{2eq}$/a	Mtonnes CO$_{2eq}$/a	Mtonnes CO$_{2eq}$/a
42	Reduced air requirements, e.g. by humidity control in paper machine drying hoods	-6	6	-	1	-7	2.3	1.5	1.5
43	Aliminium: Side worked pre-baked anode cell (SWPB) conversion	-2	5	-	1	-2	1.9	1.3	0.0
44	Integrated mills - new capacity	0	2	-	1	0	0.9	0.6	0.6
45	Scrap preheating in electric arc furnaces (secondary steel)	0	0.3	-	1	0	0.1	0.1	0.1
46	Oxygen en fuel injection in electric arc furnaces (secondary steel)	0	1	-	1	0	0.3	0.2	0.2
47	Minimills - new capacity	0	15	-	1	0	4.7	2.8	2.8
48	Replacement of mercury and diaphragm processes by membrane electrolysis (chlorine)	0	6	-	1	0	1.9	1.1	1.1
49	Semiconductors : etch - alternative chemicals	0	1	-	1	0	0.9	0.8	0.0
50	Industrial processes Adipic acid	0.1	66	-	1	0	12.4	0.0	0.0
51	Oxidation of HFC-23	0.2	7	-	1	0	6.1	5.3	0.0
52	Magnesium production: use of SO2 as protection gas	0.3	3	-	1	0	2.6	2.3	0.0
53	Industrial processes Nitric acid	0.4	22	-	1	0	19.3	16.5	0.0
54	Foam PU-one component: hydrocarbons	0.4	3	-	1	0	2.6	2.3	0.0
55	Aluminium: Vertical stud Soderberg anode (VSS) retrofit	1	0.3	-	1	1	0.3	0.2	0.0
56	Miscellaneous I (Low cost tranche)	2	12	-	1	2	10.5	9.8	9.8
57	Refiner improvements	2	1	-	1	2	0.9	0.8	0.8
58	Foam PU-pipe in pipe: pentane	2	0.1	-	1	2	0.1	0.1	0.0
59	Industrial food refrig.: hydrocarbons and NH3	3	2	-	1	4	1.8	1.5	0.0
60	Improved melting technique and furnace design	4	1	-	1	5	0.9	0.8	0.8
61	Low pressure ammonia	5	0.01	-	1	6	0.0	0.0	0.0

All measure originate from the sector report of Blok (2001a)		Data of orig. source		Assessment					
		MAC (Blok, 2001a)	GHG Red.[114]	Category*2	CF*3	MAC[115]	GHG Red.[116]	GHG Red.[117]	GHG Red.[118]
		€1990/ton	Mtonnes CO$_{2eq}$/a			€$_{2003}$/ton	Mtonnes CO$_{2eq}$/a	Mtonnes CO$_{2eq}$/a	Mtonnes CO$_{2eq}$/a
	synthesis								
62	Fertilisers - new capacity	5	0.2	-	1	6	0.2	0.2	0.2
63	Foams XPS : carbon dioxide	6	6	-	1	7	5.3	4.5	0.0
64	Aerosols : hydrocarbons	10	2	-	1	12	1.8	1.5	0.0
65	Gas turbine integration	11	0.2	-	1	13	0.2	0.2	0.2
66	Foam PU-spray: water	18	1	-	1	22	0.9	0.8	0.0
67	Foam PU-flexible faced laminate: pentane	21	1	-	1	25	0.9	0.8	0.0
68	Foam PU-discontinuous panels : pentane	27	1	-	1	33	0.9	0.8	0.0
69	Foam PU-blocks : pentane	27	1	-	1	33	0.9	0.8	0.0
70	Semiconductors: Chemical vapour deposition (CVD), NF3	28	10	-	1	34	8.8	7.5	0.0
71	Heat recovery in TMP	31	7	-	1	38	6.1	5.7	5.7
72	Foam PU-continuous panels : pentane	32	0.2	-	1	39	0.2	0.2	0.0
73	Thin slab casting techniques	33	1	-	1	40	0.9	0.8	0.8
74	Recovery of process gas from coke ovens , blast furnaces and basic oxygen furnaces (primary steel)	36	1	-	1	44	0.9	0.8	0.8
75	Miscellaneous II (High cost tranche)	47	11	-	1	57	9.6	8.9	8.9
76	Foam PU-appliances : pentane	63	0.2	-	1	76	0.2	0.2	0.0
77	Advanced reforming	65	0.1	-	1	79	0.1	0.1	0.1
78	Retrofit existing Hall-Héroult process (e.g. alumina point-feeding, computer control)	72	0.5	-	1	87	0.4	0.4	0.4
79	Semiconductors : etch – oxidation	79	3	-	1	96	2.6	2.3	0.0
80	Efficient production of low-temperature heat (heat recovery from hightemperature processes)	135	2	-	1	164	1.8	1.8	1.8
81	Wettable cathode	328	0.4	-	1	398	0.4	0.4	0.4
	Total		535.7	-			193.5	139.1	89.8

Table 77 Measures to reduce GHG in the manufacturing industry sector. The correction factors used to recalculate the emission reductions and MAC are found in table A.6.

All measure originate from the sector report of Blok (2001a)		Correction of reduction potential[119]					Correction of MAC-data
		$CF_{EU15-EU25}$	CF_{time}	$CF_{scenario\ 0}$	$CF_{scenario\ 1}$	CF_{EU-ETS}	$CF_{inflation}$
		EU25/EU15	(% left for reduction potential)				$€_{2003}/€_{1990}$
1	Application of continuous casting	1.25	100%	0%	0%	100%	1.212
2	Improved process control	1.25	100%	0%	0%	100%	1.212
3	Miscellaneous	1.25	100%	0%	0%	100%	1.212
4	Debottlenecking	1.25	100%	0%	0%	100%	1.212
5	Miscellaneous I (Low cost tranche)	1.25	100%	0%	0%	100%	1.212
6	Micellaneous II (High cost tranche)	1.25	100%	0%	0%	100%	1.212
7	Process integration, e.g. by applying pinch technology	1.25	100%	0%	0%	100%	1.212
8	Ceramics - new capacity	1.25	100%	0%	0%	100%	1.212
9	Miscellaneous I (Low cost tranche)	1.25	95%	15%	10%	100%	1.212
10	Electricity savings	1.25	95%	25%	20%	100%	1.212
11	Fractionation - various options	1.25	95%	25%	20%	100%	1.212
12	Miscellaneous I (Low cost tranche)	1.25	90%	25%	20%	100%	1.212
13	Food, beverages and tobacco - micellaneuous I (Low cost tranche)	1.25	90%	25%	20%	100%	1.212
14	Miscellaneous	1.25	90%	25%	20%	100%	1.212
15	Glass - new capacity	1.25	90%	25%	20%	100%	1.212
16	Miscelleneous - building materials	1.25	90%	25%	20%	100%	1.212
17	Raising cullet percentage in raw material	1.25	90%	25%	20%	100%	1.212
18	Paper - New capacity	1.25	90%	25%	20%	100%	1.212
19	Electricity savings	1.25	90%	25%	20%	100%	1.212
20	Cement - new capacity	1.25	90%	25%	20%	100%	1.212
21	Process integration, e.g. by applying pinch technology	1.25	90%	25%	20%	100%	1.212
22	Food, beverages and tobacco - micellaneuous II (High cost tranche)	1.25	90%	25%	20%	100%	1.212
23	Miscellaneous I (Low cost tranche)	1.25	90%	25%	20%	100%	1.212
24	Reduce clinker content of	1.25	90%	25%	20%	100%	1.212

---

[119] See chapter 4 for the definitions of the different CF.

All measure originate from the sector report of Blok (2001a)		Correction of reduction potential[119]					Correction of MAC-data
		$CF_{EU15\text{-}EU25}$	CF_{time}	$CF_{scenario\ 0}$	$CF_{scenario\ 1}$	$CF_{EU\text{-}ETS}$	$CF_{inflation}$
		EU25/EU15	(% left for reduction potential)				€$_{2003}$/€$_{1990}$
	cement						
25	Improving wet process kilns	1.25	90%	25%	20%	100%	1.212
26	Use of waste derived fuels	1.25	90%	25%	20%	100%	1.212
27	Optimisation of heat recovery of clinker cooler	1.25	90%	25%	20%	100%	1.212
28	Pulverised coal injection up to 30% in the blast furnace (primary steel)	1.25	90%	50%	40%	100%	1.212
29	Efficient CO_2 separation (e.g. by using membranes)	1.25	90%	50%	40%	100%	1.212
30	Improved drying, e.g. condensing belt drying	1.25	90%	50%	40%	100%	1.212
31	Miscellaneous II (High costtranche)	1.25	90%	50%	40%	100%	1.212
32	Cracking furnace - variuous options	1.25	90%	50%	40%	100%	1.212
33	Miscellaneous II (High costtranche)	1.25	80%	50%	40%	100%	1.212
34	Miscellaneous	1.25	80%	50%	40%	100%	1.212
35	Other non-ferro metals - miscellaneuous	1.25	80%	50%	40%	100%	1.212
36	Batch and cullet preheating	1.25	80%	50%	40%	100%	1.212
37	Miscellaneous II (High costtranche)	1.25	80%	50%	40%	100%	1.212
38	Application of multi-stage preheaters and precalciners	1.25	80%	50%	40%	100%	1.212
39	Pressing to higher consistency, e.g. by extended nip press (paper making)	1.25	80%	50%	40%	100%	1.212
40	Industrial refrigeration: hydrocarbons and NH3	1.25	80%	50%	40%	0%	1.212
41	Application of efficient evaporation processes (dairy)	1.25	80%	50%	40%	100%	1.212
42	Reduced air requirements, e.g. by humidity control in paper machine drying hoods	1.25	80%	50%	40%	100%	1.212
43	Aliminium: Side worked pre-baked anode cell (SWPB) conversion	1.25	80%	50%	40%	0%	1.212
44	Integrated mills - new ca-	1.25	80%	55%	45%	100%	1.212

All measure originate from the sector report of Blok (2001a)		Correction of reduction potential[119]					Correction of MAC-data
		$CF_{EU15-EU25}$	CF_{time}	$CF_{scenario\ 0}$	$CF_{scenario\ 1}$	CF_{EU-ETS}	$CF_{inflation}$
		EU25/EU15	(% left for reduction potential)				€$_{2003}$/€$_{1990}$
	pacity						
45	Scrap preheating in electric arc furnaces (secondary steel)	1.25	70%	55%	45%	100%	1.212
46	Oxygen en fuel injection in electric arc furnaces (secondary steel)	1.25	70%	55%	45%	100%	1.212
47	Minimills - new capacity	1.25	70%	55%	45%	100%	1.212
48	Replacement of mercury and diaphragm processes by membrane electrolysis (chlorine)	1.25	70%	55%	45%	100%	1.212
49	Semiconductors : etch - alternative chemicals	1.25	70%	100%	90%	0%	1.212
50	Industrial processes Adipic acid	1.25	100%	15%	0%	0%	1.212
51	Oxidation of HFC-23	1.25	70%	100%	90%	0%	1.212
52	Magnesium production: use of SO2 as protection gas	1.25	70%	100%	90%	0%	1.212
53	Industrial processes Nitric acid	1.25	70%	100%	90%	0%	1.212
54	Foam PU-one component: hydrocarbons	1.25	70%	100%	90%	0%	1.212
55	Aluminium: Vertical stud Soderberg anode (VSS) retrofit	1.25	70%	100%	90%	0%	1.212
56	Miscellaneous I (Low cost tranche)	1.25	70%	100%	95%	100%	1.212
57	Refiner improvements	1.25	70%	100%	95%	100%	1.212
58	Foam PU-pipe in pipe: pentane	1.25	70%	100%	90%	0%	1.212
59	Industrial food refrig.: hydrocarbons and NH3	1.25	70%	100%	90%	0%	1.212
60	Improved melting technique and furnace design	1.25	70%	100%	95%	100%	1.212
61	Low pressure ammonia synthesis	1.25	70%	100%	95%	100%	1.212
62	Fertilisers - new capacity	1.25	70%	100%	95%	100%	1.212
63	Foams XPS : carbon dioxide	1.25	70%	100%	90%	0%	1.212
64	Aerosols : hydrocarbons	1.25	70%	100%	90%	0%	1.212
65	Gas turbine integration	1.25	70%	100%	95%	100%	1.212
66	Foam PU-spray: water	1.25	70%	100%	90%	0%	1.212

All measure originate from the sector report of Blok (2001a)		**Correction of reduction potential**[119]					**Correction of MAC-data**
		$CF_{EU15-EU25}$	**CF_{time}**	**$CF_{scenario\ 0}$**	**$CF_{scenario\ 1}$**	**CF_{EU-ETS}**	**$CF_{inflation}$**
		EU25/EU15	**(% left for reduction potential)**				**€$_{2003}$/€$_{1990}$**
67	Foam PU-flexible faced laminate: pentane	1.25	70%	100%	90%	0%	1.212
68	Foam PU-discontinuous panels : pentane	1.25	70%	100%	90%	0%	1.212
69	Foam PU-blocks : pentane	1.25	70%	100%	90%	0%	1.212
70	Semiconductors: Chemical vapour deposition (CVD), NF3	1.25	70%	100%	90%	0%	1.212
71	Heat recovery in TMP	1.25	70%	100%	95%	100%	1.212
72	Foam PU-continuous panels : pentane	1.25	70%	100%	90%	0%	1.212
73	Thin slab casting techniques	1.25	70%	100%	95%	100%	1.212
74	Recovery of process gas from coke ovens, blast furnaces and basic oxygen furnaces (primary steel)	1.25	70%	100%	95%	100%	1.212
75	Miscellaneous II (High costtranche)	1.25	70%	100%	95%	100%	1.212
76	Foam PU-appliances : pentane	1.25	70%	100%	90%	0%	1.212
77	Advanced reforming	1.25	70%	100%	95%	100%	1.212
78	Retrofit existing Hall-Héroult process (e.g. alumina point-feeding, computer control)	1.25	70%	100%	95%	100%	1.212
79	Semiconductors : etch - oxidation	1.25	70%	100%	90%	0%	1.212
80	Efficient production of low-temperature heat (heat recovery from hightemperature processes)	1.25	70%	100%	100%	100%	1.212
81	Wettable cathode	1.25	70%	100%	100%	100%	1.212

Table 78 The correction factors used for the assessment of the measures in the manufacturing industry sector.

ANNEX TO CHAPTER 4.3: AGRICULTURAL AND FORESTRY SECTOR

SECTORAL LITERATURE SOURCES: AGRICULTURE AND FORESTRY

The most important literature screened in the agricultural and forestry sector is listed below:

No.	Reference	Page	Preliminary abstracted information
1	Blok_2001 bottom_up_analysis Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU. Updated Summary report on results of the bottom-up analysis March 2001 Chris Hendriks, David de Jager, Kornelis Blok, Jeroen de Beer, Jochen Harnisch, Suzanne Joosen, Dian Phylipsen, Manon Kerssemeeckers, Claire Byers and Martin Pate ECOFYS Energy and Environment Judith Bates, Christian Brand, Paul Davison, Ann Haworth and Nikolas Hill AEA Technology Environment *PS: This study is one of a set of studies in the context of the economic evaluation of emission reductions. Access to all studies through "ENV 2001: Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change" on the project-homepage.*		This report summarises the results of a two year long study using the so-called "bottom-up" methodology. The goal of this study is to identify a least-cost allocation of objectives for different sectors and greenhouse gases so that the European Union would meet its Kyoto target of –8% in 2008-2012 compared with 1990. Information on the individual mitigation options is used to calculate total emission reduction potentials and associated mitigation costs by sector, by country and by gas. The information is collected in a database called GENESIS. The analysis comprises all greenhouse gases that are subject to the Kyoto Protocol. Furthermore the analysis covers all economic sectors with an identified emission reduction potential. To determine the potential and costs of greenhouse gas emission reduction options in the EU15 in 2010, the following steps are taken: 3) Collection of base year emission data (1990/1995); 4) Preparation of a 2010 frozen technology reference level of emissions, i.e. no change in emission level per unit of production compared to 1990; 5) Identification, definition and characterisation of technical emission reduction options. In the bottom-up analysis the frozen technology reference level (FTRL) is prepared for the calculation of the emission reduction potential that could be realised during 2008-2012. The FTRL is a reference level in which no additional development to reduce emissions from 1990 onwards are included. The database GENESIS contains technology and cost information on over 250 reduction options (56 for the energy supply sector, 24 for fuel related emissions, 91 for industry, 17 for transport, 32 for households and services, 18 for agriculture and 13 for the waste sector). The study gives an approximation of the emission reduction potentials and associated costs on the sector, Member State and on the European Union level. **Note 1: Very important data source. Methodological problem: how to handle the "frozen technology reference level"**. **Note 2: In fact, it is the project's aim to update this study !**

2	Judith Bates 2001 Economic Evaluation of Sectoral Emission Reduction Objectives for Climate change: Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculte in the EU. Bottom-up analysis. Contribution to a Study for DG Environment, European Commission by Ecofys Energy and Environment, AEA Technology Environment and Naturional Technical University of Athens, Final report (updated), http://europa.eu.int/comm/environment/enveco/climate_change/agriculture.pdf, Abingdon/UK, February 2001.		This is the **sector report on agriculture** with reference to Blok et al. 2001a (bottom-up analysis -> see above). Geographically it considers EU15 (where possible). This is the **most important sector report** taken as basis for the agricultural sector. For a set of measures there are cost data available. Most of the measures concern the reduction of the enteric methane emissions. Many of the described measures refer to technologies to produce energy from manure (-> should be discussed in the energy supply sector). Only view other measures are described with cost data. Some date only relate to specific geographical or cost situations and are therefore not calculated options for all of the EU15.
3	EEA 2005a Greenhouse gas emission trends and projections in Europe 2005.	50	Greenhouse gas emissions (1990-2003) and emission trends in the EU15 (projections for 2010 (2008-2012) for the sectors 1) energy supply (excl. transport), 2) Transport, **3) agriculture,** 4) Industry (non-energy related) 5) waste management. **Findings of AF:** The EU15 greenhouse gas emissions from agriculture fell by 10% between 1990 and 2003. Both N_2O emissions from agricultural soils and CH_4 emissions from enteric fermentation fell by 21%. Based on existing domestic policies and measures, EU15 greenhouse gas emissions from agriculture are projected to decrease to 13% below the 1990 level in 2010. Projected use of **carbon sinks** for the EU15 Kyoto target: The estimated removal by forestry is 31 and by agricultural activities is 0.8 Mtonnes CO_{2eq} per year or in total about 0.7% in relation to the EU15 target of -8%. No cost data available.
4	EEA 2006 Annual European Community greenhouse gas inventory 1990-2004 and inventory report 2006. Barkman A., Fernandez R. (EEA), Gugele B., Rigler E., Ritter M. (ETC/ACC) Submission to the UNFCCC Secretariat.	444 and 12 annexes with tables	Greenhouse gas inventories, emission trends, emission factors, and removals by main greenhouse gases and by main source category for the sectors **1) energy, 2) industrial processes, 3) solvent and other product use, 4) agriculture, 5) LULUCF, 6) waste and 9) other**. Datasheets for the EU15, EU25 and country specific. Yearly data from base year 1990 to 2004.

5	Ribbenhed, M., Furusjö, E., Carlsson Reich, M., 2005, REKO luft - reduktionskostnader för luftemissionsbegränsande åtgärder, IVL Swedish Environmental Research Institute, B-report B1608.		Description: Some cost reduction data for CO_2 for the **energy, agriculture and transport sectors**. *Only in Swedish. Therefore, possibly relevant data for the agricultural sector could not be commented and distracted by INFRAS.*

6	Gillig, McCarl, Sands 2003: Integrating **Agricultural and Forestry** GHG Mitigation Response into General Economy Frameworks: Developing a Family of Response Functions. Published in Mitigation and Adaption Strategies for Global Change, Volume 9, Issue 3(July), 241-259, 2004.	19	
7	Graus, Harmelink, Hendriks 2004: Marginal GHG abatement curves for **agriculture**, ECOFYS, Utrecht, the Netherlands.	59	Costs of different agricultural measures in USD/t CO_2 (in USD_{2000}) for abatement potential in 2020 and 2050 for global regions, i.e. for OECD Europe and for Eastern Europe. MAC curves only for OECD Europe or Eastern Europe as a whole and only for 4 GHG sources: N_2O from soil, CH_4 from rice cultivation, enteric ch4 and manure CH_4. No data for EU15 or EU25 available and no cost and emission estimations for 2010.
8	Graveland, Bouwman, de Vries, Eickhout, Strengers 2002: Projections of multi-gas emissions and carbon sinks, and marginal abatement cost functions modelling for **land-use related sources**. RIVM-report 461502026, National Institute for Public Health and the Environment, Bilthoven, the Netherlands (www.mnp.nl/ieweb).	92	Estimates of GHG abatement costs (inkl. MAC curves) associated with land fills (as a source of CH_4), sewage (as a source of CH_4 and N_2O), and **carbon sequestration in forest plantations**. Bottom-up study. The potential for emission abatement is based on the GECS baseline scenario for 1995-2030 for agriculture, and land use developed with the IMAGE 2.2 model framework. World-wide and regional calculations for example for the sum of Western European countries (OECD Europe) and Eastern European Countries. Cost categories for carbon plantations: land costs (country-level data on agricultural land prices for abandoned agricultural land), forest establishment costs (incl. costs for land clearing, land preparation and plant material and planting), operation and maintenance costs (incl. management). The regional MAC curves are not underlined with datasheets.
9	IPCC 2003: Good practice guidance for **land use, land use change and forestry**.	many	UNFCCC's response to the IPCC to develop good practice guidance for land use, land use change and forestry (GPG-LULUCF), incl. definitions and reporting on carbon stock changes and GHG emissions under Art. 3.3, 3.4, and Art. 6 and 12 of the Kyoto Protocol: De-/afforestation and forest management changes.
10	McCarl and Schneider 2000: U.S. **Agriculture's Role** in a Greenhouse Gas Emission Mitigation World: An Economic Perspective. Review of Agricultural Economics. 22(1): 134-159	26	Literature review. Agricultural role as a) a source of emission reductions and b) a potential sink with focus on the **potential abatement costs**, for the **U.S.** Including **MAC curves** (estimates for the year 2000, 2010, 2020) for average costs for reduction through - enteric fermentation (CH_4),

			- livestock manure management (CH_4), - tree planting (CO_2), - biofuel for power plants (CO_2), and - ethanol use (CO_2). No indication of discount rates, annuities etc. used.
11	McCarl and Schneider 2001: Greenhouse gas mitigation in **U.S. agriculture and forestry**. Science. 294(5551): 2481-2482. Supplementary material is available at http://www.sciencemag.org/cgi/content/full/294/5551/2481/DC1	2	Estimated CO_2 emissions for the U.S. (1'562 Mtonnes CO_{2eq}) in 2000 (305 Mtonnes CO_{2eq} more than 1990). Agricultural and forestry (AF) GHG mitigation activities: i) direct emission reductions, ii) terrestrial carbon sink expansions, iii) production of replacements for emission-intensive products. AF's mitigation potential. To derive a multistrategy economic potential for AF GHG emission mitigation, alternative carbon prices were introduced. MAC curves for CH_4 and N_2O strategies, soil sequestration, afforestation and biofuel offsets are shown, but no single measure data available. **Findings of AF:** At the highest MAC price level of 500 USD/t CO_{2eq}. AF annually removes 425 Mtonnes CO_{2eq}. (= 27% of the CO_2 emissions in 1990). Total mitigation potential is price-sensitive. Low-cost strategies include soil carbon sequestration, afforestation, and to some extent non-carbon emission mitigation. At high prices, emission abatements stem mainly from forestry and biofuels. **The total contribution of non-carbon strategies is relatively small** and does not exceed 30 Mtonnes CO_{2eq} compared to 400 Mtonnes for CO_2 (at high price levels of 500 USD/Mtonnes CO_{2eq}). Other CO_2 abatements are 52 Mtonnes CO_2 for an abatement cost level of 10 USD/t CO_{2eq} (= 3.3% of the CO_2 emissions in 1990) or 146 Mtonnes CO_2 at 50 USD/t CO_{2eq} (= 9.3%) or 239 Mtonnes CO_{2eq} at 100 USD/t CO_{2eq} (= 15.3%).
12	Schneider and McCarl 2003: Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. **Agriculture and Forestry**, (Paper submitted to American Journal of Agricultural Economics), Hamburg.		Potential of major agricultural GHG emission mitigation strategies in the U.S. MAC curves at 0-300 USD/t $CO_{2\,eq}$ are shown e.g. for soil carbon sequestration on U.S. cropland (incl. conversion of cropland into pastureland), for biofuels, for afforestation of U.S. croplands (based on data from dynamic forest and agricultural sector optimization model FASOM). Figures for the U.S. only, incl. sum of emission per greenhouse gas category and carbon equivalent abatement price in USD for selected scenario. But no details are shown.

13	Sumelius et al. 2003: Marginal abatement costs for reducing leaching of nitrates in **Croatian farming systems**. Proceedings of the 25th Int. Conf. of Agricultural Economists (IAAE), 668-681.		The study is not applicable on an EU level.
14	Hediger, Hartmann, Peter, Lehmann 2005: Costs and Policy Implications of Greenhouse Gas Reduction in **Swiss Agriculture**. XIth Congress, European Association of Agricultural Economists.		This literature source refers to the Swiss study by Hediger et al. (2004; see literature described below). Study on the CO_2 sink potential of the Swiss agriculture with a bottom-up linear statistical model, integrating some dynamic elements. A Swiss case study not applicable for the EU Member states.
15	McCarl, Murray, Schneider 2001: Jointly Estimating **Carbon Sequestration** Supply from **Forests and Agriculture**. Paper prepared for presentation at Western Economics Association Meetings, July 5-8, 2001, San Francisco.		Estimates of carbon sequestration supply form forests and agriculture for the U.S. MAC curves are shown, but no details such as discount rate etc. are known. **Findings**: Primary low-cost strategies involve soil carbon sequestration and to some extent afforestation, fertilization, and manure management with estimated abatement costs varying between 50 to100 USD/t $CO_{2\ eq}$ At this price range agriculture and forestry activities in the U.S. could produce GHG offsets of approx. 140-240 Mtonnes CO_{2eq}.
16	Weiske 2005: Survey of technical and management-based mitigation measures in agriculture. MEACAP Impact of Environmental Agreements on the Common Agricultural Policy (CAP).	146	Detailed list of measures in 5 categories: 1) Measures related to livestock and poultry farming, 2) Measures on crop production, 3) Management-based measures, 4) Reduction of use of fossil fuels, 5) Political instruments. Short description of each measure and qualitative estimations on the GHG mitigation potential, the technical feasibility , the environmental added value and the cost effectiveness for each measure. No cost data.
17	Hediger, Hartmann, Peter, Lehmann 2004: Ökonomische Beurteilung und Monetarisierung der landwirtschaftlichen Leistungen im Klimaschutz.	121	Study on the CO_2 sink potential of the Swiss agriculture with a bottom-up linear statistical model, integrating some dynamic elements. Agriculture produces 12% of total GHG emissions, i.e. 63% of CH_4, 72% of N_2O, and 1.5% of CO_2. From 1990 to 2000 the GHG emissions from agriculture were reduced by 8% (which is 13% of the Kyoto reduction target). Until 2010 a further recuction by 3-10% of the agricultural GHG emissions is foreseen.

The agricultural data of the study Ribbenhed et al. (2005) could not be analysed by INFRAS because the report is only available in Swedish.

DESCRIPTION OF POLICY AND MEASURES OF THE AGRICULTURAL AND FORESTRY SECTOR

The first **section A)** gives an overview of the **agricultural measures described by Blok** et al. (2001a) or more in detail by Bates (2001). It is devided in three parts, describing 1) the sources of greenhouse gas emissions and the reduction measures (section A.1), 2) the reduction potential and marginal abatement costs according to the Blok study (Bates 2001) and other literature sources (section A.2) , and 3) the suitability as greenhouse gas emission abating measures (section A.3). The discussions in these chapters are followed the main groups of reduction measures. The section A.3) on the suitability of the Blok measures as GHG emission abating measures discusses with a comprehensive standpoint, considering long-term sustainability issues, rather than with a “narrow” micro-economic standpoint if we think that the measures described by Bates (2001) are realistic and sustainable in the long run. This discussion is necessary since the Blok measures do not account to negative external effects such as carbon leakage, animal harm or long-term sustainability issues which might induce in the national or global economy.

In the second **section B) other measures not described by Blok** et al. (2001a) or Bates (2001) in detail are discussed along the main group of reduction measures. Additional to agricultural measures, also forestry activities accountable for the Kyoto target are discussed. If available form literature review the emission reduction potential and marginal abatement costs of these measures are listed.

A list of all the measures is given in chapter 4.3 in Table 11.

A) MEASURES DESCRIBED BY BLOK

A.1) SOURCES OF GREENHOUSE GAS EMISSIONS AND MEASURES ACCORDING TO THE BLOK STUDY

Blok et al. (2001a) or the according sectoral study for agriculture (Bates 2001) describe the sources of greenhouse gas (GHG) emissions from agriculture as listed in this chapter. They distinguish three main sources of GHG emissions from agriculture:

- CH_4 emissions from enteric fermentation,
- CH_4 and N_2O emissions from manure management,
- N_2O emissions from soils.

ENTERIC METHANE EMISSIONS

Enteric fermentation from cattle is the largest single source of CH_4 emissions in the EU15 accounting 2.4% of total GHG emissions in 2004 according to EEA (2006). Enteric fermentation is the anaerobic fermentation of polysaccharides and other components of animal feeds in the gut of ruminant animals (the rumen) by micro-organisms. Food enters the rumen where it is fermented to volatile fatty acids (VFA), carbon dioxide and methane.[120] Methane emissions are dependent on animal type, age, function and production level; and on the type, amount, and digestibility of the animal feed. These factors are influenced by the livestock management system (Graus et al. 2004). Milk productivity is one of the most important factors determining the level of CH_4 emissions by dairy cattle. The increased milk productivity can partly be explained by increased energy intake, and partly by an improved feed efficiency. This is expressed in the feed digestibility. Higher feed digestibility reduces the portion of carbon intake that is transformed to methane in ruminants (EEA 2006). Measures to reduce methane production include **improved feed conversion efficiency** by optimising livestock diets, **improved animal productivity** through the use of feed additives or breeding, and **improved rumen efficiency** through use of feed additives (Bates 2001). The main driving force of CH_4 emissions from enteric fermentation is the **number of cattle, which was 14% below 1990 levels in 2004** (EEA 2006). CH_4 emissions from enteric fermentation stem also from sheep, goats and swine. The measures to reduce enteric CH_4 emissions are described in the following sub chapters (for details see Bates 2001).

a) Improving feed conversion efficiency – replacing roughage with concentrates

Replacement of roughage, which contains a high proportion of structural carbohydrate (fibres), with concentrates, can improve propionate generation in the rumen and decrease emissions of methane.

Options to improve feed conversion efficiency can lead to higher methane emissions per animal, but methane emissions per unit of meat or milk production are reduced. It has been assumed that production in the EU remains constant and increases in productivity lead to a decrease in animal numbers.

---

[120] The carbon dioxide and methane are mainly removed by eruction (through the mouth or gut of the animal) with a small proportion of methane is absorbed in the blood and is eliminated through the lungs. Fermentation is also coupled to microbial growth and the microbial cell protein synthesised forms the major source of protein for the animal (Bates 2001).

b) Improve feed conversion efficiency – include more non-structural carbohydrates in concentrate

Research has shown that increasing the level of non-structural carbohydrate (NSC) or starch in the diet can reduce methane production by as much as 20% for a 25% increase in the level of NSC (Moss 1994; in Bates 2001, p.43). This is because the NSC is readily fermented, and leads to a reduced protozoal population and lower rumen pH. However, this can give rise to an overall depressed ruminal fermentation, which may lower the conversion of feed energy into animal product and may be **detrimental to the animal's health**, leading to e.g. acidosis and fertility problems if NSC levels are too high (Bates 2001, p. 43). Inclusion of more NSC could also decrease nitrogen excretion, which could reduce N_2O emissions (from manure deposited during grazing or stable manures subsequently applied to the land). Starch (or NSC) may typically already form between 10 to 30% of the total diet for cattle in the EU. Feed compounds are available which range from 100% fibrous material to 100% starch based material and can be used by the farmer to balance diet. The farmer may already control proportions of starch and fibrous material as they influence milk properties (such as fat content and protein content; Bates 2001).

c) Improving feed conversion efficiency – high fat diet

The addition of large amounts (up to 10%) of fats to dairy cows' diets meets energy requirements, and reduces methane production by increasing the proportion of proprionic acid produced. High levels of fat can however greatly impair the entire fermentation process in the rumen (Bates 2001, p. 44). Current levels of fat in concentrates in the EU are about 2% (Bibby 2000 in: Bates 2001).

d) Increasing rumen efficiency with propionate precursors

By increasing the presence of propionate precursors such as the organic acids, malate or fumarate, more of the hydrogen in the rumen is used to produce propionate, and methane production is reduced. Propionate precursors can be introduced as a feed additive for livestock receiving concentrates. The propionate precursor, malate, also occurs naturally in grasses, and it is possible that plant breeding techniques could be used to produce forage plants with high enough concentrations of malate. Considerable research is needed, but if these techniques were successful then this mitigation option could then also be used with extensively grazed animals (Bates 2001, p. 46). It is estimated that if successful, the option could reduce methane emissions by up to 25%, (ADAS 1998, in Bates 2001), and that there could be other benefits to the livestock industry such as improved feed degradation which would be likely to reduce feed costs. Another possible benefit would be a reduced incidence of acidosis (a digestive disorder) in high producing dairy cows and intensively reared cattle, which could lead to considerable cost savings. As propionate precursors naturally occur in the rumen, they are likely to be more readily acceptable than antibiotics or chemical additives. Propionate precursors would be given to animals as daily supplements. Supplements are given to dairy cows year-round, but non dairy cattle can only be fed with supplements when they are housed inside which is assumed on average to be 40% of the year.

e) Improved level of feed intake with improved genetics

Increasing the level of voluntary feed intake for cattle can change the volatile fatty acids (VFA) composition of the rumen so that less acetate and more propionate is formed, leading to lower methane emissions per unit of animal product (Bates 2001, P. 41). In addition to this change there is a reduction in the 'maintenance' losses. Total methane emissions per animal will increase, so that reductions are only obtained if overall production levels are kept constant, meaning that the number of animals will decrease due to increased productivity (Bates 2001, p. 41). The baseline scenario of the Blok study (Blok et al. 2001a) already include an assumption for a continued increase in productivity for dairy cows which is not accounted with this option. In the EU, average feed intakes are often already very close to voluntary feed level intakes and increases in intake will only be possible if they are accompanied by an improvement in livestock genetics. The problems that may be associated with higher genetic merit cattle (such as lameness, mastitis etc) may tend to restrict their use to larger dairy farms (e.g. in UK, Italy, Germany, the Netherlands; Bates 2001, p. 42).

GREENHOUSE GAS EMISSIONS FROM ANIMAL HUSBANDRY AND MANURE MANAGEMENT

Both methane and nitrous oxide can be emitted from manure. The way manure is handled and stored in stables determines the amount of methane production and emissions. If manure is kept under anaerobic conditions with temperatures higher than about 15°C, methanogenic bacteria will produce methane. Research indicates that anaerobic digestion of manure has the potential to reduce both methane and nitrous oxide emissions (Graus et al. 2004).

Methane emissions depend on the quality of the manure, which in turn depends on the feed intake and digestibility, the methane producing potential which varies by animal type and quality of feed consumed, the way the manure is managed and the climate. Measures to reduce enteric methane emissions are also likely to reduce methane emissions from manure. Other measures to reduce methane emissions include reducing anaerobic decomposition of manure by better control of the manure management system (this particularly applies to indoor housing of pigs) or controlled anaerobic digestion (Bates 2001). CH_4 emissions from manure management are a key source category for cattle and swine and did not change between 1990 and 2004 in the EU15 (EEA 2006). In some member states emissions from swine are most important (Portugal, Spain, Denmark), while in others (Luxembourg, Ireland, UK) emissions from cattle are more important.

Nitrous oxide emissions are influenced by nitrogen availability, soil moisture content and temperature. It is therefore important to match the nitrogen load to crop demand to help reduce emissions but also to reduce other impacts such as nitrate leaching (Bates 2001). N_2O emissions from manure management are representing only a small fraction in most inventories. The N_2O emission factor for solid manor is much higher than for liquid manor (EEA 2006).

The measures that are evaluated in Blok et al. (2001a) and Bates (2001) are:

- Slowing down anaerobic decomposition of manures in livestock housing or cellars through regular emptying and storage of manure outside the housing or manure cellars;
- Controlled anaerobic digestion of the manure in either a small scale on-farm plant or a large centralised digester;
- Ensuring aerobic decomposition either by daily spreading or composting.

f) Manure storage: Slowing down anaerobic decomposition of manure in stables

Systems with a slatted floor are very common in intensive pig farming operations and manure is often stored there for some months (Bates 2001, p. 61/62). This creates relatively high emissions, as the manure begins to anaerobically decompose, particularly as the housing is often heated, especially in cooler countries of the EU. Emissions can be reduced by moving the slurry to an outdoor storage system. For example, it has been found that at a temperature of 10°C emissions from slurry can be 60 to 100% lower than emissions from slurry stored in animal housing kept at 20°C (Zeeman 1994, in Bates 2001, p. 62). Manure can be regularly moved to an outdoor storage system using a manure slide.

Ensuring that the manure pit or stable is completely cleared out can also help to reduce methane emissions. In general 10 to 15% of slurry remains in the manure storage after emptying, and this manure acts as an inoculant, so that anaerobic decomposition of fresh manure added to the system begins quickly. Experimental work has shown that when inoculant was not present methane production had not begun within 60 days (Zeeman 1991, in Bates 2001). Ensuring that all manure is removed from the cellar can be done by rinsing out the manure cellar or stable floor. As long as this is done using cleansed water separated from the collected slurry, the volume and dry matter content of the manure is not increased so that storage facilities for the slurry do not need to be increased (Bates 2001, p. 62).

It is estimated overall that this option might lead to a 10% reduction in emissions (compared to the baseline trend) from intensive pig rearing systems, where pigs are housed indoors in stables with slatted floors and manure is currently stored for long periods (i.e. greater than a month; Bates 2001, p. 63). In some countries such as the Netherlands, systems to move slurries to outdoor stores and to completely empty slurry pits are currently being installed to help reduce ammonia emissions. It is assumed that this option is applied only in countries with a cooler climate (all EU countries except Greece, Italy, Portugal and Spain), and only to larger herds and it is also considered applicable only where manures are currently stored in pits for greater than 1 month. From IPCC guidelines (1997), 73% of pig slurry in Europe is stored in this way (Bates 2001, p. 62).

ENERGY PRODUCTION (BIOFUELS)

g) Controlled anaerobic digestion: farm-scale and centralised

Anaerobic digestion (AD) is the bacterial fermentation of organic material under controlled conditions in a closed vessel. The process produces biogas which is typically made up of 65% methane and 35% carbon dioxide with traces of nitrogen, sulphur compounds, volatile organic compounds and ammonia (Bates 2001, p. 64). This biogas has a typical calorific value of 17-25 MJ/m^3 and can be combusted directly in modified gas boilers, used to run an internal combustion engine or simply flared. Applying this process to animal manures ensures that most of the carbon is ultimately converted to carbon dioxide before being released to atmosphere. Typically, between 40% and 60% of the organic matter present is converted to biogas. The remainder consists of a relatively odour free residue with an appearance similar to peat, which has some value as a soil conditioner and also, with some systems, a liquid residue which has potential as a fertiliser. Other perceived benefits of AD are reduced odour problems, and avoiding prosecution for water pollution (Bates 2001, p. 64).

Anaerobic digestion plant can be small scale, located on a farm, or large centralised plant can be used. In the case of the latter, other organic wastes may also be taken in (e.g. brewery wastes, waste from food processing plant) to ensure a consistent supply of waste all year round with a moisture content and nutrient balance suitable for the anaerobic digestion plant. This can have the additional advantages of higher methane yields from such wastes compared to manures, and additional income from charging a gate fee for disposing of the waste. Such centralised plant need to be located in areas with a high concentration of farms to ensure that transport distances and hence costs for the wastes are kept low. The large centralised plants which have been built in Denmark are of this type (Bates 2001, p 64/65). Two typical options are assessed in Bates (2001): a) farm scale digestion and b) centralised plant which also takes in organic waste. Bates (2001) distinguishes also between plants in cooler and warmer countries and between only heat producing plants and combined heat and power producing plants, resulting in the following types of anaerobic digestion plants (Blok et al. 2001a, Bates 2001):

- Centralised anaerobic digestion – cooler countries
- Farm scale anaerobic digestion – cooler countries (heat&power)
- Farm scale anaerobic digestion – cooler countries (heat only)
- Farm scale anaerobic digestion – warmer countries (heat&power)
- Farm scale anaerobic digestion – warmer countries (heat only)

According to Bates (2001, p 65) anaerobic digestion (AD) offers an opportunity to significantly reduce emissions from manures, and theoretically emissions can be reduced to almost zero. In practice however, methane may still be emitted at various stages of the AD process (i.e. emissions during storage, leakage of biogas from the AD plant itself or emissions from digestate) although many of these sources can be minimised by good practice. Overall while the centralised plant is likely to be more leak tight and better controlled, this may be offset by emissions from storage pre-digestion. It is therefore assumed that a reduction of 50% reduction is achievable in emissions for both farm scale and centralised plant in cool climates for manures which would otherwise be stored as liquid slurry and hence have relatively high methane emissions. For warmer climates, where the methane emissions from such manure storage systems are estimated to be over three times higher (IPCC 1997, in Bates 2001, p. 66), a reduction potential of 75% is assumed. For all plants, a mixture of non-dairy, dairy and pig manure is assumed based on the average livestock mix in the EU15 (for cool and warm countries).

An additional benefit of utilising biogas from AD plant to produce heat and electricity is that this will offset CO_2 emissions resulting from fossil fuel energy sources. These avoided emissions will be much higher than any CO_2 emissions associated with collecting and transporting the waste. For example, the latter have been estimated as about 30g/kWh of electricity produced from an AD plant compared to an 'avoided emission' from fossil fuel electricity generation of about 450 g/kWh (assuming gas fired generation). It is possible that anaerobic digestion may also reduce N_2O emissions compared to slurry storage, but this has not yet been demonstrated conclusively, and is therefore not considered in the estimates of emissions reductions in (Bates 2001, p. 66).

CROPLAND MANAGEMENT, AGRICULTURAL SOILS

Agricultural N_2O emissions derive from three principal sources (IPCC 1996, in: Bates 2001):

- direct emissions from soil nitrogen e.g. applied fertilisers (both manures and artificial), the mineralisation of organic soils and crop residues;
- emissions from livestock wastes in store;
- indirect emissions from nitrogen lost to the agricultural system e.g. through leaching, runoff or atmospheric deposition.

Nitrous oxide is produced by the processes of denitrification and nitrification. Denitrification is the microbial reduction of nitrate or nitrite to dinitrogen or N-oxides and occurs in anaerobic, flooded soils, and in anaerobic microsites in otherwise aerated soils. Nitrous oxide is readily soluble, and surface water draining from agricultural fields contains dissolved N_2O, which is later denitrified or lost to the atmosphere. Leached nitrate can be denitrified in ground or surface waters to provide a source of N_2O as large as direct emissions from soils (Bouwman 1990, in Bates 2001, p. 11). Nitrification is the oxidation of ammonium to nitrite or nitrate. The principal environmental parameters affecting N_2O emissions are the availability of a nitrogen source, moisture and temperature, with nitrogen availability being the most important (Colbourn 1993, in Bates 2001, p. 11). Agricultural management has a major influence on nitrogen availability and environmental conditions, through, for example, fertiliser applications, livestock waste handling and residue management (see manure management) or operations affecting the structure, aeration and pH of soils.

At present the recommended methodology for estimating N_2O emissions from soils (IPCC 1997) assumes that 1.25% of the nitrogen contained in mineral fertilisers is released directly as N_2O, with further N_2O emissions arising from volatilisation and subsequent deposition of NH_3 and NO_x from the application of fertilisers (Bates 2001, p. 12).

h) Fertiliser Management: Reduction of use of (synthetic) fertiliser, increase N-efficiency, demand management

Diminished use of fertilizer reduces the N_2O emissions. As a positive side-effect of less Nitrogen use the chemical content of runoff from agricultural lands affecting water pollution, water quality and ecology of streams, rivers, lakes and aquifers could alter and improve the characteristics of the waters in these regions for use by non-agricultural water consumers (McCarl and Schneider 2000). Options which farmers could utilise now and which were also considered likely to be applicable in EU countries were (Worrell 1994, in: Bates 2001):

- **Improved maintenance of fertiliser spreaders** to ensure uniform spreading and reduce under fertilisation of some areas and over fertilisation of others;
- **Fertiliser free zones (avoiding fertiliser loss):** The Reduction of fertiliser losses by maintaining a fertiliser free zone on the edge of fields to prevent losses into ditches etc. at side of fields;
- **Optimisation of fertiliser distribution geometry** to prevent losses into ditches at the side of fields.

Reductions in EU Member States are likely to vary, depending on current fertilisation rates, crop and soil type, crop productivity and climatic differences. Soil analysis to determine mineral N quantities can also help to ensure that nitrogen applications are optimised. However while providing an accurate indication of mineral N at the start of the growing season, a number of other factors such as summer weather, leaching rates etc, can influence N availability and make it difficult to optimise levels.

Optimising applications by ensuring application of fertiliser nitrogen (N) at recommended economic optimum levels, and by taking better account of nitrogen applied as manure were examined by Bates (1998). The study found that in broad terms, it appeared that (in the UK) little or no account is being taken for the residual N from the previous crop or from the nitrogen available from organic fertiliser applications. This means that levels of N application are higher than the recommended economic optimum.

The **introduction of set aside** is one reason for the decline in fertiliser use since the early 1990s. In estimating the impact that set-aside might have on fertiliser use and N_2O emissions it is important to note that it is possible that set-aside could be used to grow non-food crops, and hence fertiliser use on set-aside would not be zero, and that it is also possible that the retention of set aside would encourage farmers to maximise margins on cropped areas, leading to changes in crop types grown which could lead to an increase in average fertiliser use per ha in cropped areas. Bates (2001) estimated the possible impact of set aside by assuming a reduction in nitrogenous fertiliser use on the 10% set-aside of 50 kg N/ha.

i) Precision farming

Precision farming technologies (also referred to as site specific management) are becoming available and may offer opportunities for reducing the risk of environmental pollution as well as improving farm profits. Precision farming technologies such as yield mapping, Global Positioning System (GPS) and automatic sensing of crop and soil differences from vehicles, aircraft or satellites, now allow crop performance and output to be measured in different areas of an individual field. In addition, advance farm machinery provides farmers with the capability to vary inputs across a field. The reduction in N application that use of precision farming techniques might deliver is not yet clear, although it seems likely that they do offer a way of optimising inputs without reducing yield (Bates 2001, p. 18).
According to field experiments in Germany (Schmerler and Basten 1999, in Bates 2001, p. 18) yearly N savings of between 2 and 52 g N/ha were achieved on winter wheat, maize and spring barley using variable rate application (compared to uniform treatment), and yields increased by between 0.02 and 0.39 t/ha.

MEASURES DESCRIBED BUT NOT CONSIDERED BY BLOK

Enteric methane emission: Improving feed conversion efficiency – treatment of roughage

One way to improve feed conversion efficiency is the treatment of low quality roughages such as straw and other crop by products either mechanically or chemically to improve their digestibility. Mechanical treatments include chopping, grinding, milling or pelleting of feeds. Chemical treatments include the use of ammonia, urea formaldehyde and sodium hydroxide. In general however these treatments are not thought to be applicable in the EU, where animals already receive a carefully managed diet, and are therefore **not considered** in the Bates study (Bates 2001, p. 39).

Enteric methane emission: Increasing rumen efficiency with other options than with propionate precursors

The option to improve feed conversion efficiency (with more non-structural carbohydrates in concentrates) described above indicated how changes in concentrates could increase rumen efficiency, although with possible animal health implications. A number of other possible options have been identified which could increase rumen efficiency without threatening animal health (Bates 2001):

a) propionate precursors (described above: the only option for which cost data is available);

b) hexose partitioning;

c) direct fed microbials (acetogens or methane oxidisers);

d) genetic engineering;

e) an immunogenic approach.

Almost all of these options **need more R&D**, to provide conclusive evidence of the reductions possible and to assess costs.

Enteric methane emission: Increasing animal productivity through the use of additives

Animal productivity can be improved through a number of feed additives. This will lead to a reduction in total enteric emissions of methane only if the total amount of milk or beef produced remain constant. Possible options for increasing productivity are (Bates 2001, p. 47):

- **Probiotics** which are microbial feed additives containing live cells and a growth medium. They are already widely available in the EU, and are used to improve animal productivity. From an analysis of published results from more than 1000 cows, Wallace and Newbold (1993) calculated that probiotics stimulated milk yield by 7.8%, and from 16 trials using growing cattle, they showed an average increase in liveweight gain of 7.5%. Further research is required to confirm whether there is any additional effect on methane production per se. Even without a direct effect on methane production, there would be a reduction in methane production per unit of production (e.g. per litre of milk). The cost of using probiotics has been estimated at about 5440 $€_{1990}$/t CH_4 for dairy cattle and 11'332 $€_{1990}$/t CH_4 for non dairy cattle (Bates 1998), although as this does not allow for the benefits of increased productivity it may be an overestimate.
- **Ionophores** are chemical feed additives that increase productivity by adjusting several fermentation pathways. On average, an 8% increase in feed conversion efficiency has been observed (Chalupa 1988) and a reductions in methane production (of up to 25%; Van Nevel and Demeyer 1992); the persistence of this reduction is however unproven. **Ionophores are fed only to beef animals in the EU**. Their use in dairy cows is not permitted because a withdrawal period is required before human consumption. The cost of using Monesin, an ionophore to reduce emissions was estimated at about -10'000 $€_{1990}$/t CH_4 (Hendriks et al. 1998) due to savings on feeding costs and particularly on extra beef production.
- **Antibiotics and halogenated compounds** are also currently used for growth simulation and can also induce a shift in the pattern of rumen fermentation in favour of propionate, thus re-

ducing methane emissions. In the case of antibiotics use, methane emission reductions of 4 to 31% have been observed (Hendriks et al. 1998) and in the case of halogenated compounds (e.g. chloroform, carbon tetrachloride and methylene chloride) reductions of up to 90% might be possible.

› **Bovine somatotropin (BST)** is a genetically engineered metabolic modifier approved for use in some countries to enhance milk production from dairy cows. Again, this is not a popular consumer choice for enhancing animal productivity and its use now banned by all EU Member States.

The cost of using probiotics has been estimated at about 5'440 $€_{1990}$/t CH_4 (259.0 $€_{1990}$/t CO_{2eq}) for dairy cattle and 11'332 $€_{1990}$/t CH_4 (539.6 $€_{1990}$/t CO_{2eq}) for non dairy cattle (Bates 1998), although as this does not allow for the benefits of increased productivity it may be an overestimate. The cost of using Monesin, an ionophore to reduce emissions was estimated at about -10'000 $€_{1990}$/t CH_4 (-476.2 $€_{1990}$/t CO_{2eq}; Hendriks et al. 1998) due to savings on feeding costs and particularly on extra beef production (in Bates 2001, p. 48).
The use of chemicals and antibiotics to increase animal productivity is increasingly becoming unpopular to the consumers of animal products, and the European Commission has banned the use of a number of feed additives. There might be considerable consumer opposition to the use of these options (Bates 2001, p. 48).

Manure management/application: Aerobic decomposition – daily spreading

Emissions from manure spread to land are estimated to be a small fraction (perhaps only 1%) of emissions from manure stored in a liquid form under anaerobic conditions. Minimising storage of manure by daily spreading can thus minimise methane emissions. However daily spreading can have a number of undesirable impacts including:

› emissions of N_2O and ammonia, although the latter can be minimised by incorporating the manure into the soil;
› nitrate leaching if the application of nutrients in the manure does not match crop requirements;
› risk of run-off causing water pollution during times of high rainfall;
› damage to soil structure from large numbers of vehicle movements.

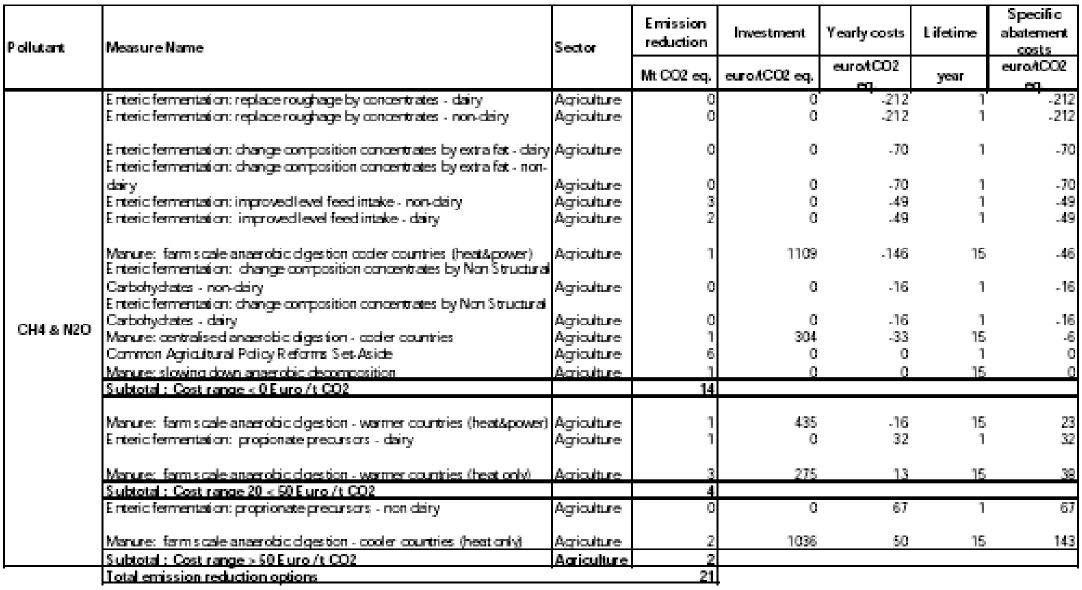
The daily spreading of manure is relatively common in Western Europe for dairy farms, with 20% of dairy manure estimated to be treated this way (IPCC 1997). Further implementation of this option is not considered desirable because of the other environmental impacts outlined above, and initiatives such as the Nitrates Directive designed to ameliorate such impacts.

Manure treatment: Aerobic decomposition – composting and aerobic treatments

Aerobic treatments can be applied to liquid manures through aeration and to solid manures by composting. Aeration involves dissolving sufficient oxygen in the liquid manure to allow bacteria to oxidise the organic carbon. Systems for aeration involve mechanical methods for passing air through the liquid, usually driven by electric motors. Aeration may leave up to 70% of the total organic load (Burton et al. 1997, in Bates 2001, p. 75) which may subsequently degrade anaerobically if the liquid manure is stored, and losses of 4-11% of the total nitrogen as nitrous oxide have been reported from the aeration of liquid pig manure (Burton et al. 1993). Therefore there is considerable uncertainty as to the effectiveness of this treatment option (Bates 2001).
Solid manures can be aerobically treated by composting. This may require dewatering of liquid manures or addition of other dry organic materials to increase porosity and penetration of air. Also organic material may have to be added to increase the carbon to nitrogen ratio to levels suitable for composting. As with aeration, composting requires energy input to turn the compost ensuring good mixing and air penetration, and this will lead to some CO_2 emissions.
Aerobic decomposition of manures can increase N_2O emissions unless the manure is rapidly dried. Emissions of methane from solid storage of manure are considerably less than from liquid storage, but the combined global warming potential (when both CH_4 and N_2O emissions are taken into account) of farmyard manure systems can be similar to – or in some cases higher than – slurry based systems, due to the higher N_2O emissions. The composting of solid manures and further implementation of this option is therefore according to Bates (2001) not considered in Blok et al. (2001).

A.2) REDUCTION POTENTIAL AND MAC ACCORDING TO THE BLOK STUDY

OVERVIEW



Pollutant	Measure Name	Sector	Emission reduction	Investment	Yearly costs	Lifetime	Specific abatement costs
			Mt CO2 eq.	euro/tCO2 eq.	euro/tCO2 eq.	year	euro/tCO2 eq.
CH4 & N2O	Enteric fermentation: replace roughage by concentrates - dairy	Agriculture	0	0	-212	1	-212
	Enteric fermentation: replace roughage by concentrates - non-dairy	Agriculture	0	0	-212	1	-212
	Enteric fermentation: change composition concentrates by extra fat - dairy	Agriculture	0	0	-70	1	-70
	Enteric fermentation: change composition concentrates by extra fat - non-dairy	Agriculture	0	0	-70	1	-70
	Enteric fermentation: improved level feed intake - non-dairy	Agriculture	3	0	-49	1	-49
	Enteric fermentation: improved level feed intake - dairy	Agriculture	2	0	-49	1	-49
	Manure: farm scale anaerobic digestion cooler countries (heat&power)	Agriculture	1	1109	-146	15	-46
	Enteric fermentation: change composition concentrates by Non Structural Carbohydrates - non-dairy	Agriculture	0	0	-16	1	-16
	Enteric fermentation: change composition concentrates by Non Structural Carbohydrates - dairy	Agriculture	0	0	-16	1	-16
	Manure: centralised anaerobic digestion - cooler countries	Agriculture	1	304	-33	15	-6
	Common Agricultural Policy Reforms Set-Aside	Agriculture	6	0	0	1	0
	Manure: slowing down anaerobic decomposition	Agriculture	1	0	0	15	0
	Subtotal : Cost range < 0 Euro / t CO2		14				
	Manure: farm scale anaerobic digestion - warmer countries (heat&power)	Agriculture	1	435	-16	15	23
	Enteric fermentation: propionate precursors - dairy	Agriculture	1	0	32	1	32
	Manure: farm scale anaerobic digestion - warmer countries (heat only)	Agriculture	3	275	13	15	38
	Subtotal : Cost range 20 < 50 Euro / t CO2		4				
	Enteric fermentation: proprionate precursors - non dairy	Agriculture	0	0	67	1	67
	Manure: farm scale anaerobic digestion - cooler countries (heat only)	Agriculture	2	1036	50	15	143
	Subtotal : Cost range > 50 Euro / t CO2	Agriculture	2				
	Total emission reduction options		21				

Table 79 EU15 average costs and total potential (Mtonnes CO_2 equivalent) for emission reduction of methane options in the agricultural sector (summary table). Source: Blok et al. (2001a).

ENTERIC METHANE EMISSIONS

a) Improving feed conversion efficiency – replacing roughage with concentrates

Reductions in emissions of 6.2% for dairy cattle and 8.2% for other cattle are estimated to be possible, assuming a) an extra concentrate intake of 1 kg/day dry matter (DM) and a reduction of 0.5 kg DM/day in intake of roughage for mature animals (0.7 and 0.35 kg DM/day respectively for young animals; Gerbens 1999), b) that methane emissions are reduced by 10% for a 20% increase in diet due to a shift in volatile fatty acids (VFA) composition, and c) that milk and beef production remains constant. The cost of this option in Western Europe is estimated by Gerbens (1999, in Bates 2001, p. 42) to be -4450 $€_{1990}$/t CH_4 (-211.9 $€_{1990}$/t CO_{2eq}).

b) Improve feed conversion efficiency – include more non-structural carbohydrates in concentrate

Gerbens (1999, in Bates 2001, p. 44) estimated achievable reductions are 13.1% and 7.8% in dairy and other cattle respectively, assuming a) concentrates form 40% of gross energy in the diet in the EU, b) that 5 kg of structural carbohydrate concentrate is replaced with 5 kg of concentrate with a NSC:SC ratio of 1:3 i.e. 25% of SC concentrate is replaced by NSC concentrate, and c) that there is no difference in price between NSC and SC concentrates. Gerbens (1999) estimated that a realistic implementation level by 2010 would be 25%; i.e. this option could be applied to 25% of cattle in the EU and that the cost of the option is estimated to be -330 $€_{1990}$/t CH_4 (-15.8 $€_{1990}$/t CO_{2eq}) assuming that SC and NSC concentrates cost the same.

c) Improving feed conversion efficiency – high fat diet

Gerbens (1999, in Bates 2001) estimated that replacing 'low fat' concentrates with concentrates with a high fat content (of about 7%) could reduce reduction in emissions from dairy cows in Western Europe by 7.3% and in other cattle by 4.3% (Gerbens 1999, in Bates 2001, p. 44). This reduction assumes that for every kg of concentrate replaced, CH_4 emissions are reduced by 2%. Gerbens (1999) estimated that by 2010, this option might be implemented in 25% of the herd. The cost of this option is estimated at -1480 $€_{1990}$/t CH_4 (70.5 $€_{1990}$/t CO_{2eq}), based on the assumptions that concentrates supply 40% of gross energy in the diet, that energy contents of low and high fat concentrates are 20 and 20.66 MJ/kg dry matter and that high and low fat concentrates have the same cost (Gerbens 1999, in Bates 2001, p. 45).

d) Increasing rumen efficiency with propionate precursors

Supplements are given to dairy cows year-round, but non dairy cattle can only be fed with supplements when they are housed inside which is assumed on average to be 40% of the year. Annual emissions from dairy cows are therefore reduced by 25% and those from non-dairy cattle by 10%. It is assumed that feed can be reduced by 5% due to increased productivity and that by 2010 25% of cattle receive propionate precursors. The cost of the propionate precursor is about 2010 $€_{1990}$/t, which, on the basis of an 80g/day supplement, and allowing for reduced feed costs, gives a cost of 672 $€_{1990}$/t CH_4 (32.0 $€_{1990}$/t CO_{2eq}) for dairy cows, and 1400 $€_{1990}$/t CH_4 (66.7 $€_{1990}$/t CO_{2eq}) for non-dairy cattle.

e) Improved level of feed intake with improved genetics

It is estimated that continued improvements in genetic merit could bring about reductions of up to 20% in methane emissions from dairy cows. It is estimated that an increase in the feed intake of mature animals and young animals of 1 and 0.7 kg dry matter per day respectively would lead to a reduction in emissions of 7.8% for dairy cattle and 9.6% for other cattle (Gerbens 1998, in Bates 2001, p. 41). This assumes that methane emissions are reduced by 10% for a 20% increase in diet due to a shift in volatile fatty acids (VFA) composition, and that milk and beef production remain constant. The cost of this option is estimated as -1030 €$_{1990}$/t CH_4 (49.0 €$_{1990}$/t CO_{2eq}) taking into account savings from reductions in overall feed level and losses from beef and milk production due to livestock reduction (Bates 2001, p. 41

GREENHOUSE GAS EMISSIONS FROM ANIMAL HUSBANDRY AND MANURE MANAGEMENT

f) Manure storage: Slowing down anaerobic decomposition of manure in stables

Costs vary according to the type of pig (e.g. sows or fattening pigs), farm size and type of storage system. Capital costs for manure slide and rinsing system per animal and tonne of methane avoided are very high (300'000-1'510'000 €$_{1990}$/t CH_4 or 14'300-71'900 €$_{1990}$/t CO_{2eq} saved per year), so that this measure is not cost-effective if applied for methane mitigation only. However as discussed above this option also reduces ammonia emissions and is likely to be implemented for this reason. It is assumed that all countries where this option is applicable will also be taking action to reduce ammonia emissions. No costs are therefore allocated to this option. The reduction achieved by the option is assumed to be 10% or 35.4 kt CH_4 in 2010 for the EU15, and the overall reduction achieved by the measure (compared to the baseline trend of Blok et al. 2001a) is 1.7% (Bates 2001).

ENERGY PRODUCTION (BIOFUELS)

g) Controlled anaerobic digestion: farm-scale and centralised

Both farmscale and centralised plant can be used to produce heat and or electricity, which the farm owner may utilise, or in the case of centralised plant may be sold. The plant also produces a digestate, which potentially can be sold as a soil conditioner. The opportunity to use the plant to produce electricity rather than heat also has a significant influence on cost, due to the higher value of electricity. In the study of Bates (2001) costs for farm scale plant assume that there is no income from the digestate, and that the plant is used to produce heat which is used on farm. This provides an upper limit for cost-effectiveness, but is likely to be quite common (assumed to be applicable for 75% of farms). In the remainder of cases, (25%) it is assumed that electricity production and utilisation are also possible, leading to a better cost-effectiveness. Costs are given for this to provide a lower bound. For centralised plant, costs are based on the assumption that electricity is produced and sold to a utility or industry. Cost data are available for farmscale plant in several countries and show considerable variation. The cost-effectiveness varies from 75 €$_{1990}$/t CO_{2eq} (heat production only in the Netherlands) to -40 €$_{1990}$/t CO_{2eq} (heat and power production in Germany). Costs for a centralised plant are based on the costs of a UK Plant for which the marginal abatement costs are estimated to be -8 €$_{1990}$/t CO_{2eq} (for details see Bates 2001).

CROPLAND MANAGEMENT, AGRICULTURAL SOILS

h) Fertiliser Management: Reduction of use of (synthetic) fertiliser, increase N-efficiency, demand management

There is a considerable amount of ongoing research into improving understanding of emissions mechanisms, and examining the impact that different agricultural practices might have on N_2O emissions at the field and farm scale. This could help to improve emission estimates, by for example establishing relationships that take account of soil type and climate. Such work would also allow the impact of mitigation measures to be established with more certainty.

The costs of different options examined by Worrell (1994) were estimated for various crops based on increases in capital, labour and maintenance costs, savings in fertiliser purchase and allowing for interactions between measures (for details see Bates 2001). The cost-effectiveness per t N_2O has been calculated accounting for only direct emissions (1.25% of N is lost as N_2O) and for direct and indirect emissions (1.9% of N is lost as N_2O).

For successful implementation of **optimising N application by allowing for manure**, farmer awareness of this additional source of N would need to be raised and there may be a cost to educational programmes designed to achieve this. For example, in the UK, a simple computer model has already been developed to enable farmers to estimate the N value of manures applied, and adjust inorganic fertiliser applications (Chambers et al. 1999, in Bates 2001, p. 26). This is available at a low cost (about 63 €) to the farmer. Other potential costs include determining the N content of the manure accurately. Costs for this are 33 € per sample (Levington Agriculture 2000, in Bates 2001). For this measure the cost effectiveness of a) direct and b) direct and indirect emissions in €$_{1990}$ per t CO_{2eq} is calculated for different crops.

For the **continuation of set-asides** projected changes in N_2O emissions are available for specific sites. Continuance of set aside would be undertaken as part of an ongoing package of European agricultural CAP reforms, with a variety of agricultural and environmental objectives and is hence considered as a ‘zero-cost’ measure in terms of N_2O mitigation (for details see Bates 2001).

For all these measures the cost effectiveness of a) direct and b) direct and indirect emissions in €$_{1990}$ per t CO_{2eq} is calculated for different crops. Yet the reduction potential for the EU member states is not known, since it depends on local conditions that cannot be covered in a general database.

COST-EFFECTIVENESS OF REDUCTION OF N_2O EMISSIONS FROM SOILS: REDUCTION OF USE OF SYNTHETIC FERTILISER				
Measures	**Crops**	**Total costs per t CO_2 reduction (direct emissions only) [€/t $CO_{2\,eq}$]**	**Total costs per t CO_2 reduction (direct and indirect emissions) [€/t $CO_{2\,eq}$]**	**Comments**
Improved maintenance of fertiliser spreaders	grass	-43	-28	Investment costs: 0 €/t $N_{fert.}$ O&M costs: 63 €/tN_{fert}/a
	maize	-43	-28	
	potato	-39	-26	
	sugar beet	-24	-16	
	wheat	-25	-16	
	barley	-41	-27	
Fertiliser free zone on the edge of fields	grass	-45	-30	Investment costs: 0 €/t $N_{fert.}$ O&M costs: 0 €/tN_{fert}/a loss in income from yield reduction: 41-113 €/tN_{fert}/a depend. On crop.
	maize	-29	-19	
	potato	-39	-26	
	sugar beet	-15	-10	
	wheat	-24	-16	
	barley	-27	-18	
Optimisation of fertiliser distribution geometry	grass	-32	-21	Investment costs: 587 €/t $N_{fert.}$ O&M costs: 0 €/tN_{fert}/a
	maize	-33	-21	
	potato	-27	-18	
	sugar beet	-2	-1	
	wheat	-2	-1	
	barley	-31	-20	
Precision farming system	grain maize	-270	-178	Capital costs: 109'000 € Annual costs: 57'000 € (incl. maintenance with 5% of capital costs) Fertiliser and cost savings in E_{1990}/ha: 47 € (grain maize), 27 € (winter wheat), 24 € (spring barley).
	wheat	-40	-27	
	barley	-24	-16	
Optimizing N application by allowing for manure	potato	0.8	0.5	
	wheat	-37	-24	
Continuation of set-aside	Only projected changes in N_2O emissions but no cost data			

Table 80 Examples of cost effectiveness with the efficient use of fertiliser.

i) Precision farming

See table above.

A.3) SUITABILITY AS GREENHOUSE GAS EMISSION ABATING MEASURES

DEFINITION OF SUITABILITY

This chapter discusses for each of the measures suggested by Bates (2001) and Blok et al. (2001a) whether we regard it as cost effective in a broader economic and sustainable sense (considering 'hard' and 'soft' costs of a measure). Also we discuss whether the emission reduction potential of a measure is relevant and therefore if the measure is relevant for the EU25 (and not only for very few countries within the EU). As a result we suggest for each of the measures described by Bates (2001) and Blok et al. (2001a) whether it should be considered as a Kyoto target option. Possibly we think of some measures that they should be regarded as Kyoto target options, but no cost figures for all of the EU15 are available.

Kauppi et al. (2001) give some ideas what a comprehensive analysis of carbon mitigation measures should consider, being applicable also for other than carbon-related GHG abatement measures:

- Potential contributions to C pools over time:
- Sustainability, security, resilience, permanence, and robustness of the C pool maintained or created;
- Compatibility with other land-use objectives;
- Leakage and additionality issues;
- Economic costs;
- Environmental impacts other than climate mitigation;
- Social, cultural, and cross-cutting issues as well as issues of equity; and
- The system-wide effects on C flows in the energy and materials sector.

The measures described in Bates (2001) and Blok et al. (2001a) are mainly technologically driven. The described costs of those measures are viewed in a rather strict and theoretical sense:

- Some cost relevant factors are neglected in the cost figures, such as how to get the farmers to accept and implement a certain technical measure, and some investments are assumed to be undertaken for other reasons than for the option described (i.e. as a NH_3-reducing measure).
- The estimated costs do not include leakage, leading to increased emissions elsewhere (outside of the EU). Leakage can occur across both spatial and temporal boundaries.
- Negative effects on the animal well-being are accepted (which would also create additional veterinary costs).

- It is assumed that with an increase of total methane emissions per animal, methane reductions could only be obtained if overall production levels are kept constant, meaning that the number of animals will decrease due to increased productivity (Bates 2001, p. 41).
- None of the enteric methane reducing measures are planned and they lack of an EU policy framework to push these measures.

We consider that a cost effective measure should be cost-effective in a broader sense. So, costs created by leakage effects in other countries or costs to maintain animal health should be considered in a minimum. Cost-effectiveness should therefore be seen with an overall economic view based on the principles of sustainability (including also the 'social' and 'ecological' part of sustainable agriculture). External costs such as leakage should be accounted globally. With this view, Kyoto target options should not only reduce GHG emissions in the short term (within the Kyoto timeframe 2008-2012) but the emission reductions should basically not be undone with another increase in emission after Kyoto. We consider cost effective measures to have a long-term emission reduction potential which is at least on the level of the targeted Kyoto emissions reduction.

ENTERIC METHANE EMISSIONS

Together with the proposition of the reduction measures of enteric methane emissions Bates (2001) claims some precaution for accounting this measures (Bates 2001, p. 49-50): "In general Member States appear to have few substantive policies to reduce enteric fermentation emissions although several anticipate improving productivity and digestive efficiency. … In considering the actual reductions which might be achieved by 2010, it should be remembered that **the viability and effectiveness of many of these options in actual farming situations has yet to be proven**. Some demonstration of options leading to an increase in confidence is likely to be necessary before there is a significant uptake of measures. Furthermore, **no work has yet been done on how options might interact with each other, and it is not at all clear that it will be possible to combine options**. Even where this is possible, it is unlikely that the reductions achieved would be additive."

a) Improving feed conversion efficiency – replacing roughage with concentrates

The following reasons indicate that GHG emissions reduction from this measure could not be seen as cost effective and sustainable in a comprehensive standpoint, considering long-term sustainability issues:

- At present there are some trends in the other direction in that the use of home grown forages (rather than concentrates) appears to be increasing (Bates 2001).
- It should also be noted that production of industrial concentrates is an energy intensive process (with associated CO_2 emissions) and that the production of high quality feed could lead to increased emissions of CO_2 and N_2O from increased fertiliser production and application (Bates 2001).
- Other environmental implications related to the adoption of this option include (Bates 2001):
  - It could promote a conversion of grassland to cropland to grow concentrates. This could result in a CO_2 release from the mineralization of soil organic matter.
  - In many European regions with intensive cattle production, grasslands represent the only possible agricultural use of the land due e.g. to climatic constraints or erosion. Discouraging extensive grazing could lead to an abandonment of these lands.
  - Extensive grazing can be an environmentally valuable form of agriculture in terms of biodiversity, land conservation and landscape enhancement.
  - The use of home grown forages allows a relatively tight nutrient cycle since manure is returned to the area where the animal feed was grown. An increase in concentrates may require the import of concentrates onto the farm, leading to an accumulation of imported nutrients on the farm land. Tightening the nitrogen cycle is one way in which N_2O emissions from agriculture can be reduced.

Therefore we suggest that GHG emissions reduction from this measure **should not be targeted** within the EU.

b) Improve feed conversion efficiency – include more non-structural carbohydrates in concentrate

This measure can be detrimental to the animal's health, leading to e.g. acidosis and fertility problems if non-structural carbohydrates (NSC) levels are too high (Bates 2001). Furthermore it would be difficult to communicate to the farmers that they should change the sort of concentrates favouring a higher level of NSC in it because of lower methane emissions prospected and despite of possible animal health implications.

Therefore we suggest that this measure **should not be targeted** as a GHG emissions reduction measure within the EU.

c) Improving feed conversion efficiency – high fat diet

First of all, Bates (2001, p. 44) noticed that high levels of fat can greatly impair the entire fermentation process in the rumen. Secondly it can be stated that additional fat in animal diet can either derive from vegetable or animal sources and is not sustainable with a global view. The use of vegetable fat is in competition with food production which means that instead of a higher fat content in animal diet the same vegetable fats could serve human nutrition (or potentially biofuel production). In case of using animal fat it is the same as far as the fat source is not waste material. Using fat coming from animal wastes should not be practiced though.[121]

Therefore we suggest that this measure **should not be targeted** as a GHG emissions reduction measure within the EU.

d) Increasing rumen efficiency with propionate precursors

As far as we know there are currently no animal health implications or other negative impacts foreseen with the application of propionate precursors. On the other hand, propionate precursors naturally occur in the rumen and their supplementary intake could lead to benefits to the livestock industry such as improved feed degradation or reduced incidence of acidosis in high producing dairy cows and intensively reared cattle. We suggest that **propionate precursors could be a possible target option** to reduce GHG emissions for livestock receiving concentrates.

e) Improved level of feed intake with improved genetics

High genetic merit cows can have increased problems with fertility, lameness, mastitis and metabolic disorders, and their management is more complex. Implementation of this approach could be stalled by animal welfare implications. Furthermore, improving productivity is already being widely implemented across the EU and should not be forced. As some improvement in productivity is already allowed for in the baseline, it is also important not to overestimate the reductions that might be achieved through improved genetics (Bates 200,p. 50).

Therefore we suggest that this option **should not be targeted** as a GHG emissions reduction measure within the EU.

---

[121] BSE would not have been an existing problem if animals were not fed with animal wastes.

Carbon leakage:

The Blok study (Blok et al. 2001a) does not (or only partly) consider carbon leakage effects. It is estimated that all the emission reducing measures described under “enteric fermentation” induce an increase of GHG emissions from non-abating countries which are assumingly higher than the reduction of emissions by abating (Annex B) countries. As an example, the increase of concentrates implies a higher production rate of concentrates. Due to the globally increasing demand of farm land over the last years the additional demand on concentrates could often only be satisfied with the generation of farm land on cost of forest land (such us tropical rainforest). With a global focus (beyond the edge of Kyoto Parties) large quantities of concentrates are produced in non-abating countries (i.e. in Brasilia or Argentine) and on deforested land.

Due to these carbon leakage effects it is suggested not to account the GHG emission reduction measures resulting from higher concentrate feeding to the abatement potential. Also, it must be noted, that dairy production in Europe is more intensive than the IPCC guidelines suggest (EEA 2006).

GREENHOUSE GAS EMISSIONS FROM MANURE MANAGEMENT

f) Manure storage: Slowing down anaerobic decomposition of manure in stables

This measure is considered as meaningful. Nevertheless we have difficulty accepting the GHG emissions potential for 2010 described in Bates (2001) when it is assumed that the very high capital costs should not be counted. Bates (2001) concluded that the emission reductions are only achieved as windfall gains when the capital investments are financed for ammonia reduction intentions. Seeing it from this point of view, it is a very cost-effective measure, but including all the effective costs (i.e. the high capital costs) the marginal abatement costs would be rather high.

ENERGY PRODUCTION (BIOFUELS)

g) Controlled anaerobic digestion: farm-scale and centralised

In the working paper “common framework and methodology” underlying this report it is clearly written that “the sector energy supply includes all activities where energy is converted (or ‘produced’)”. This includes “as well steam and power production in industrial plants or industrial bio-fuel production in agriculture”. In this sense all the measures described by Blok et al. (2001a) and Bates (2001) under controlled anaerobic digestion are producing energy (heat and/or power).

Therefore these measures should not be accounted to the agricultural sector but to the energy supply sector.

CROPLAND MANAGEMENT, AGRICULTURAL SOILS

h) Fertiliser Management: Reduction of use of (synthetic) fertiliser, increase N-efficiency, demand management

We do consider the improved use of fertilisers aiming in a overall reduction of fertiliser applied as very important to reduce the N_2O emissions. Therefore we would like to account these measures for the GHG reduction potential from agriculture. Yet the reduction potential for the EU member states is not known, since it depends on local conditions that cannot be covered in a general database. Additional, the cost effectiveness of these measures is difficult to estimate on a general level for the EU.

i) Precision farming

Also, precision farming on large cropland farms could be an option to be considered as one of the EU's GHG reduction measure. Yet the reduction potential for the EU member states is not known, since it depends on local conditions that cannot be covered in a general database. Additional, the cost effectiveness of these measures is difficult to estimate on a general level for the EU.

Other measures described but not considered in Blok et al. (2001)

We do agree with Blok et al. (2001a) and Bates (2001) that the following measures should not or cannot be considered as GHG reduction measures for the EU for different reasons described earlier:

› Improving feed conversion efficiency – treatment of roughage
› Increasing rumen efficiency with other options than with propionate precursors
› Increasing animal productivity through the use of additives

B) OTHER POLICIES AND MEASURES (NOT DESCRIBED BY BLOK)

B.1) OTHER SOURCES OF GREENHOUSE GAS EMISSIONS IN AGRICULTURE AND FORESTRY

ENTERIC METHANE EMISSIONS

We have no suggestions for other measures than described in Blok et al. 2001a to reduce enteric methane emissions.

Greenhouse gas emissions from animal husbandry and manure management

Animal husbandry: Reduction of grazing, increase in in-door animal husbandry

No detailed description.

Reduction of ammonia emissions (indirect emissions, atmospheric deposition)

No detailed description.

ENERGY PRODUCTION (BIOFUELS)

Bioenergy from lingo-celluloid wastes

No detailed description.

Bioenergy crop production

No detailed description.

CROPLAND MANAGEMENT, AGRICULTURAL SOILS

Rice production

Irrigated rice is a major source of methane. In rice cultivation, methane is mainly produced in the last step of the anaerobic breakdown of organic matter in wetland rice soils. Rice production ecosystems vary. Typically there are four different rice cultivation ecosystems worldwide (Graus et al. 2004):

- Upland cultivation: Upland dry land is considered to have minimal methane production compared to especially irrigated and deep water and tidal systems.
- Irrigated rice: Methane emissions are generally high and account for 80% of methane emissions from rice. Irrigation patterns and organic inputs are key factors.

- Rain fed rice: The emissions are lower than by irrigated rice systems due to irregular water supply, and depend on timing and drying intervals. Methane emissions are difficult to mitigate due to limited options of water management.
- Deepwater rice: Methane emissions can be kept at low level with no tillage and mulching with rice straw.

Asia accounts for 94% of total rice production worldwide. In Europe, rice cultivation is occurring in five EU15 countries: France, Greece, Italy, Portugal, and Spain. Italy is by far the largest producer of rice in Europe, with 2297 km^2 of rice cultivation in 2004, followed by Spain with an area of 1182 km^2. All countries but Italy are reporting rice production under a continuously flooding regime (deepwater rice), while in Italy the practice of multiple aeration is predominant (irrigated rice). In Italy rice paddies are flooded with 15-25 cm of water usually from April-May to August. During this field submersion time two or three water drainage periods, 2 to 4 days each, can happen in 85% of the rice paddies (irrigated rice), a clearly uninterrupted submersion in 13-14% (deepwater rice) and about one month delayed submersion in 1-2% (EEA 2006). The average emission from continuously flooded fields (deepwater rice) appears to be only half of those from multiple-aerated intermittently flooded rice fields. Intermittently flooded, single-aerated paddies have emissions in between.

According to Graus et al. (2004) most of the options for mitigating CH_4 emissions from rice cultivation involve changing the water management regime to reduce the time over which anaerobic conditions in flooded fields occur, or alter the amendments to the soils to inhibit methanogenesis. The measures include (Graus et al. 2004):

- **Alternate flooding/drainage:** this measure reduces anaerobic conditions. Estimated CH_4 reduction efficiency: 60%.
- **Rice straw compost:** substitutes for fresh rice straw; lowers organic matter. Estimated CH_4 reduction efficiency: 61%.
- **Phosphogypsum:** addition of this by-product (3 t/ha) releases sulphate, which inhibits methanogenesis. Estimated CH_4 reduction efficiency: 32%.
- **Direct wet seeding:** replaces transplanting; exact CH_4-reducing mechanism unclear. Estimated CH_4 reduction efficiency: 19%.
- **Midseason drainage and no organic matter:** reduces anaerobic conditions; lowers organic matter source. Estimated CH_4 reduction efficiency: 76%.
- **Replace urea with ammonium sulphate (AS):** replaces commonly used urea; sulphate inhibits methanogenesis. Estimated CH_4 reduction efficiency: 20%.

Barriers for rice CH_4 mitigation are (1) no financial incentives to adopt mitigation technologies, (2) no insurance facility for adopting techniques, (3) uncertainty regarding mitigation potential and (4) impacts on yields and lack of knowledge on alternative techniques (Lantin et al. 2003).

With view to the EU25 the change of management systems for rice production is only relevant for Italy, but not for the EU as a whole.

Manure application: near-soil placing of liquid manure

No detailed description.

Field burning of agricultural residues

No detailed description.

Cropland management (affecting the structure, aeration and pH of soils, carbon sequestration)

According to Leifeld et al. (2003) in Switzerland the carbon stock in agricultural soils has about 38.5% of the organic carbon of Switzerland (or 170 Mtonnes OC) with additional 3.1% (14 Mtonnes OC) of carbon bound in biomass.

There are a variety of agricultural land-management practices that might enhance sinks or limit emissions. For croplands, the IPCC Guidelines identify three potential sources or sinks of CO_2 from agricultural soils: 1) net changes in organic carbon stocks of mineral soil associated with changes in land use and management, 2) emissions of CO_2 from cultivated organic soils, 3) emissions of CO_2 from liming of agricultural soils. Total annual emissions/removals of CO_2 are calculated by summing emissions/removals from these sources (IPCC 2003). However the agricultural carbon sinks are country wise eligible under the Kyoto protocol (but not for CDM).

Examples of potential measures to increase carbon contents on cropland with management practices are described as follows:

› **Tillage intensity reduction:** Reduced tillage (e.g. direct cropping instead of ploughing) increases soil carbon sequestration and reduces fossil fuel use and accompanying emissions. Addition environmental-quality attributes such as reduced levels of erosion or increasing soil water-holding capacity leading to the need for less irrigation water can be expected (McCarl and

Schneider 2000 and 2001).[122] Therefore reduced tillage has a GHG reduction potential for the Kyoto targets.

Example (IPCC 2003): Switching from conventional to reduced or zero tillage may cause modifications in soil physical, chemical and biological properties, as well as in water regimes, nutrient dynamics, fossil fuel use, and other factors related to the greenhouse gas balance of the system. Factors that may be taken into consideration for measuring and monitoring, in addition to changes in the soil organic carbon pool are:
a) Changes in nitrous oxide and methane emissions from soil.
b) Changes in carbon dioxide emissions by transportation of agro-chemicals used in addition to those in the baseline case.
c) Changes in carbon dioxide emissions by burning of fossil fuels in farm equipment.

In Switzerland 2.8% of today's cropland is managed with no tilling (more than 8'000 ha out of almost 290'000 ha; Hediger et al. 2004). The estimated sequestration rate with no tillage management is estimated at 0.33±0.1 t C/ha*a. with an estimated actual sink rate of 2.72±0.82 kt C/a. and a maximum sink rate of 95.5±28.9 kt C/a in case that all the cropland is managed with no tilling (direct cropping). But higher N_2O emissions have to be expected along with this option (Hediger et al. 2004).

- **Residue Management**
- **Crop rotation, crop mix alteration, increase of winter cover crops and perennials**
- **Conversion of arable land in continuous grassland:** Hediger et al. (2004) estimates for Switzerland that the conversion of arable land (almost 190'000 ha) in continuous grassland could at an annual estimated sequestration rate of 0.42–0.46 t C/ha*a. could have a maximum sink rate of 122–133 kt C/a for Switzerland in case that all the arable land is conversed. N_2O emissions could be expected in case of intensively managed grasslands or grassland soils could alternatively be a N_2O sink if managed extensively over years (Hediger et al. 2004). No cost data for the EU are known.
- **Wetland management: Renaturation and extensivation of agriculturally used organic soils**: In Switzerland almost 30% of today's wetland is managed (about 5'000 of 17'000 ha; Hediger et al. 2004). The sequestration rate for the renaturation of management organic soils is estimated at 0.45±0.2 t C/ha*yr. with an additional estimated rate for oxidative carbon loss on peat soils of 9.5±2.2 t C/ha*yr. This results for Switzerland in a maximum sink rate of 91–271 kt C/a in case that all the wetland managed is renaturated. The netto sink rate of all the GHG considered (CO_2, N_2O, CH_4) accounting for all the emission reductions and the increase of methane emissions is estimated to be positive over a 200 years period (Hediger et al. 2004). No cost data for the EU are known.

---

[122] Reductions in intensity of tillage have in cases been found to require additional use of pesticides for weed, fungus, and insect management. This may have deleterious effects on ecological systems, runoff, and water quality (McCarl and Schneider 2000).

Nevertheless it must be seen that all the carbon sink measures on cropland have a limited sequestration potential because there are only temporary measures. The sequestration potential is characterised with a saturation of the carbon content in the soil. Also, the carbon sinks are potential carbon sources, when the captured carbon in the soil could again be released in case of land use or management changes. It is important for accounting the GHG to keep this carbon captured in the soil. This implies no change in agricultural land use or management practises after the reach of the maximum carbon stock. If a farmer comes back to tillage the captured carbon might be released at once (Hediger et al. 2004). In case of carbon sequestration on agricultural soils changes of CH_4 and N_2O emissions also have to be considered.

Therefore cropland management measures could possibly be cost-efficient measures to reach the short-term Kyoto target. With view to the long-term carbon reduction potential carbon sequestration on agricultural land cannot be seen as effective options with regard to cost-effectiveness or carbon reduction potential.

REDUCTION OF USE OF FOSSIL FUELS

Energy-efficient building design

Theoretically the energy-saving potential of farm buildings should also be considered in the agricultural sector, unless it is considered in the housing sector. With view to the Kyoto target such measures to increase the energy-efficiency of buildings (including stables) are truly not cost-effective. But in the long-term these could be cost-effective measures to be considered.

Energy efficiency (fuel, heat, power) in farm-based processes

There are several farm-based processes that are very energy intensive. As on the energy demand side it should also be considered if and how the overall energy consumption – especially for these energy intensive processes – could be reduced (or replaced) for the commitment period and in the long run. The following are examples of energy intensive processes to be considered:

› **Greenhouses/horticulture:** Compared to other agricultural activities, horticulture under glass consumes by far most energy. Consumption fluctuates according to the severity of the winter and mainly depends on the kind of covering material, the air-tightness of the house, the kind of heating system, the greenhouse equipment, irrigation system etc. A breakdown of energy consumption in Dutch agriculture and horticulture shows that in 2001 84% (125.4 PJ) of the total energy in this sector (149 PJ) is consumed by horticulture under glass (LEI 2003).[123] There have been hardly any observable changes in other consumption, such as heating for animal accommodation, lighting and machines.

- › **Technical hay ventilation**
- › **Crop drying processes**

BEHAVIOURAL CHANGE ON DEMAND SIDE

Reduction of milk and meat consumption

Reductions in demand could be brought about by changes in diet, either by reducing consumption of milk and beef, or substitution of alternative products such as soya milk, or poultry or pork. Changing diets to reduce protein consumption could also have a beneficial effect on agricultural emission of N_2O by reducing the N needs for food demand per capita. Reducing production will obviously have implications for farm profitability and for the size of the agricultural sector (Bates 2001). Also this behavioural change and the emission reduction potential out of this potential option is not considered here because it is not a technical measure.

AFFORESTATION/REFORESTATION/DEFORESTATION

Afforestation or reforestation

Under the definitions of the Marrakesh Accords (Art. 3.3. of Kyoto protocol), both afforestation and reforestation refer to direct, human-induced conversion of land to forest from another land use. The definitions do not include replanting or regeneration following harvest or natural disturbance, because these temporary losses of forest cover are not considered deforestation. For the identification of units of land, afforestation and reforestation are usually discussed together because the two definitions differ only by the time since the area was last forested (and because the same carbon reporting and accounting rules apply to both activities). Afforestation occurs on land that has been forest more recently (though not since 31 December 1989; IPCC 2003).
With the conversion of agricultural lands to tree plantations carbon is subsequently stored in the forest soil, the growing tree and any products which take up long term residence in buildings etc. Some authors show that programs designed to move agricultural lands into forestry could have deleterious effects on the traditional forest sector, leading to either deforestation of traditional parcels or reduced incomes (McCarl and Schneider 2000).

---

[123] Compared to <0.5% for arable farming, 1.4% for floriculture (in the open), 3% for grazing livestock holdings, 5% for factory farms and 6% for other farms.

Example (IPCC 2003): Tree planting on non-forested sites generally increases carbon stocks. These tree-planting projects could include planting with commercial timber species, planting with non-commercial native species, planting with multipurpose species (e.g., fruit trees, shade trees for coffee), or a combination of these species groups. Tree planting may also change emissions of greenhouse gases, in particular CO_2, CH_4 and N_2O. Factors that may be taken into consideration for measuring and monitoring, in addition to changes in carbon stocks in pools defined by the Marrakesh Accords and decisions of the COP, are:
a) Changes in emissions of greenhouse gases by burning of fossil fuels or biomass resulting from site preparation, monitoring activities, tree harvesting, and wood transportation.
b) Changes in nitrous oxide emissions caused by nitrogen fertilization practices.
c) Changes in nitrous oxide emissions from planting of leguminous trees.
d) Changes in methane oxidation due to alteration of groundwater table level (particularly in high organic soil types), tree planting and soil management.

Afforestation often results not as consequence of a measure planned but as an uncontrolled gain of forest starting with i.e. in-growth of bushes on previously farmed land. This in-growth of non-forest land since 1990 can be attributed to the Kyoto target if bushes/trees could be considered as forest (with a height of at least 3 m). Nevertheless within this reporting these should be regarded for in the baseline scenario. For planned afforestation with tree planting activities (which could actually be referred to as additional and for which costs could be calculated with the availability of MAC) it is now too late to be considered for the Kyoto period (2008-2010) since these afforestation activities would not lead to forests in the Kyoto timeframe (with trees over 3 m). We suggest that only (the part of the) measures with emission reductions which are accountable for the Kyoto target – with effective emission reductions between 2008-2012 – should be included in our scenarios. This means that either the measure is part of the baseline scenario or could be neglected if no emission reductions within the Kyoto timeframe are expected.

Therefore abatement costs or even MAC curves for afforestation activities being accountable for the Kyoto target and not being part of the baseline scenario must not be calculated.

Deforestation

Deforestation refers to direct, human-induced conversion of forest to non-forest land. The definitions do not include harvest that is followed by regeneration since this is considered a forest management activity. Forest cover loss resulting from natural disturbances, such as wildfires, insect epidemics or wind storms, are also not considered direct human-induced deforestation, since in most cases these areas will regenerate naturally or with human assistance. Human activities (since 1990) such as cropland management or the construction of roads or settlements, that prevent forest regeneration by changing land use on areas where forest cover was removed by a natural disturbance, are also considered direct human-induced deforestation (IPCC 2003).

GHG emissions reduction potential and MAC

According to the EEA (2005) reporting the projected use of carbon sinks for achieving the EU15 Kyoto target is relatively small. Ten Member States (Austria, Denmark, Finland, Ireland, Italy, the Netherlands, Portugal, Slovenia, Spain and the United Kingdom) have provided preliminary estimates of their intended use of carbon sinks to achieve their burden-sharing targets (EEA 2005a). The estimated removal by forestry activities (af-, re- and deforestation under Article 3.3 of the Kyoto Protocol) by 2008-2012 is 31 Mtonnes CO_2 per year for the EU15. Additionally, Slovenia expects a net removal of about 0.4 Mtonnes CO_{2eq} per year (EEA 2005a, p. 43). This totals a yet estimated removal of 31.4 Mtonnes CO_2 per year for the EU25 with afforestation, reforestation and deforestation activities. Unfortunately no cost estimates for forestry sink activities could be found for the EU.

FOREST MANAGEMENT

Under the Marrakesh Accords (Art. 3.4. of Kyoto protocol) “forest management” is defined as “a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner”. Forest harvest practice alterations and harvest followed by regeneration is considered a forest management activity. It includes both natural forests and plantations meeting the forest definition in the Marrakesh Accords with the parameter values for forests that have been selected and reported by the Party. Natural, undisturbed forests should not be considered either an anthropogenic source or sink and are excluded from national inventory estimation. Parties must decide by 31 December 2006 whether to include forest management in their national accounts and document their choices in the submission to the UNFCCC Secretariat.

There are two approaches conceivable that countries could choose to interpret the definition of forest management. In the **narrow approach**, a country would define a system of specific practices that could include **stand-level forest management activities**, such as site preparation, planting, thinning, fertilization, and harvesting, as well as **landscape-level activities** such as fire suppression and protection against insects, undertaken since 1990. In this approach the area subject to forest management might increase over time as the specific practices are implemented on new areas. In the **broad approach**, a country would define a system of forest management practices (without the requirement that a specified forest management practice has occurred on each land), and identify the area that is subject to this system of practices during the inventory year of the commitment period (IPCC 2003).

Examples of country-specific decisions include the treatment of tree orchards or grazing lands with tree cover. Since most countries (if not all EU member states) have in place policies to manage forests sustainably, and/or use practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner, the total area of managed forest in a country will often be the same as the area subject to forest management.

Changes in carbon stock (as well as emissions of non-CO_2 gases) in forests can derive from five carbon pools, which are aboveground biomass,[124] belowground biomass, dead wood, litter, and soil organic matter. Other carbon losses in managed forest land include losses from disturbances such as windstorms, pest outbreaks, or fires.

Examples (IPCC 2003):

1) Reduced impact logging: Some logging practices in forests can cause damage to both vegetation and soils that seriously impair regeneration. If adopted as part of sustainable forest management, reduced impact logging is a technique that aims at minimizing these negative impacts, thus reducing carbon dioxide emissions and improving the carbon removal capacity of regrowth. Factors that may be taken into consideration for measuring and monitoring, in addition to changes in carbon stocks in relevant pools, particularly dead wood and soil organic carbon pools, are (IPCC 2003):

a) Changes in CO_2 emissions from burning of fossil fuels due to improved harvesting and logging logistics.

b) Changes in nitrous oxide and methane emissions from soil.

2) Enrichment planting on logged-over forest or secondary growth forest: Certain forest harvesting practices, such as selective logging, may cause poor residual tree growth. Enrichment planting with high-growth, commercially-valuable, or multipurpose species usually increases carbon stocks. Factors that may be taken into consideration for measuring and monitoring in addition to changes in carbon stocks in relevant carbon pools are (IPCC 2003):

a) Changes in nitrous oxide emissions from soils due to nitrogen inputs (fertilizers or use of leguminous trees).

b) Changes in carbon dioxide emissions by burning of fossil fuels for site preparation, logging and wood transportation, in addition to those in the baseline case.

c) Changes in methane oxidation caused by changes in vegetation and soil management.

GHG emissions reduction potential and MAC

According to EEA (2005, p. 43) only Portugal and Slovenia have already decided to account for forest management (under Article 3.4 of the Kyoto Protocol) leading to an additional carbon sequestration of around 0.8 and 1.3 Mtonnes CO_2 per year.

Unfortunately no cost estimates for forestry sink activities could be found for the EU. Kauppi et al. (2001) state that mitigation costs through forestry can be as low as about 20–100 USD/t C in developed countries (= 5.4–27 USD/t CO_2 or 4.5–22.5 €/t CO_2 [125]).

---

[124] Annual biomass loss is a sum of losses from commercial roundwood fellings, fuelwood gathering, and other losses (IPCC 2003).

[125] Conversion factor of 3.7 tons of CO2 = 1 ton of C; a uniform exchange rate of 1.20 $/€ is used in the project.

The European climate change programme estimates that potentially 93-103 Mtonnes CO_2 could be sequestered through the enhancement of sink activities in the agricultural and forestry sectors (EEA 2005a, p. 43). The carbon sequestration potential of afforestation and reforestation measures, forest management and natural forest expansion in the EU15 Member States is estimated 33 Mtonnes CO_2 until 2010 if the measures are fully implemented, compared to business as usual (EU 2006, p. 19).

ANNEX TO CHAPTER 5.2: METHODOLOGY AND MODELS FOR HDV ASSESSMENTS

The technology potentials and the related costs were elaborated by questionnaires and interviews of engineers at manufacturers and research companies. Additional an extensive literature study was carried out, but nearly no useful numbers on the reduction of fuel consumption and the related costs were found in literature on the actual technologies for 2007 and later.

The reduction potential and the related costs were simulated with the model GLOBEMI, which is employed to calculate the Austrian emission inventory for the transport sector since 1995. In the model first the Business as Usual (BAU) scenario was implemented for EU 25 HDV traffic. Then the technology potentials elaborated before were implemented into the new registered HDV from 2008 on (or later, depending on the technology and the related time range assumed for development and testing). The model simulates the fleet turnover in a realistic way to assess the total reduction potential.

The costs were calculated from the technology potentials, where both, emission reduction and costs were defined in percent change compared to the EURO III HDV. Thus the €/t CO_2 are available.

For detailed analysis of technology potentials for several measures the model Phem (passenger car and Heavy duty vehicle Emission Model) was used.

The model GLOBEMI

Fuel consumption and emissions for road transport are calculated with the model GLOBEMI. A detailed description is given in (Hausberger, 1997). The software was not changed compared to the emission inventory for Austria for the year 2003 (Hausberger, 2004).

GLOBEMI was developed for the calculation of emission inventories in larger areas. The method is described briefly in the following.

The program calculates vehicle mileages, passenger-km, ton-km, fuel consumption, exhaust gas emissions, evaporative emissions and suspended PM 10 of the road traffic. The calculation is performed as balances of transport and emissions over time spans which can be selected by the user. The balances use the vehicle stock and functions of the km driven per vehicle and year to assess the total traffic volume of each vehicle category. The total traffic is split into urban, road and motorway driving.

Model input is:

1) the vehicle stock of each category split into layers according to the propulsion system (SI, CI etc.), cylinder capacity classes or vehicle mass,

2) the emission factors of the vehicles according to the year of first registration and the layers from 1)
3) The passengers per vehicle and tons payload per vehicle
4) Optional either
    a) the total gasoline and diesel consumption of the area under consideration
    b) the average km per vehicle and year

In version a) GLOBEMI calculates the average km per vehicle and year iteratively in a way that the total amount of gasoline and diesel defined in the input data is used. Since the year 2004 this option is used no longer used for the Austrian emission inventory. Due to the high amount of fuel sold in Austria but used in other countries, the model did not provide useful results for 2002 ff.

Figure shows a schematic picture of GLOBEMI. Following data is calculated:

a) km driven per vehicle and year or total fuel consumption
b) total vehicle mileages
c) total passenger-km and ton-km
d) specific emission values for the vehicle fleets [g/km], [g/t-km], [g/pass-km]
e) total emissions and energy consumption of the traffic (fc, CO, HC, NO_x, particulate matter, CO_2, SO_2 and several unregulated pollutants

According to the calculation method, all results are available for the single vehicle layers according to 1) and the year of first registration if necessary.

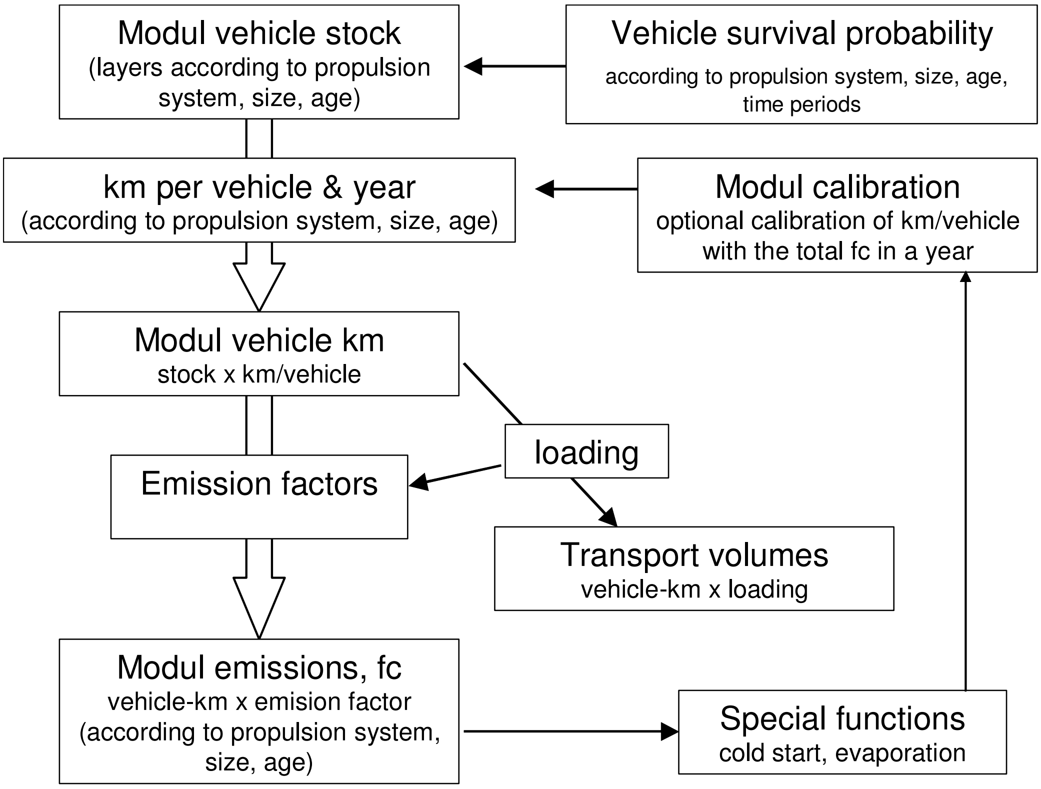


Figure 44 Schematic picture of the model GLOBEMI.

The calculation is done according to the following method for each year:

(1) Assessment of the vehicle stock split into layers according to the propulsion system (SI, CI,..), cylinder capacity classes (or vehicle mass for HDV) and year of first registration using the vehicle survival probabilities and the vehicle stock of the year before.

$$stock_{\mathrm{Jg_i},\mathrm{year\,i}} = stock_{\mathrm{Jg_i},\mathrm{year\,i-1}} \times \text{survival probability}_{\mathrm{Jg_i}}$$

(2) Assessment of the km per vehicle for each vehicle layer using age and size dependent functions of the average mileage driven. If option switched on, iterative adaptation of the km per vehicle to meet the total fuel consumption targets.

(3) Calculation of the total mileage of each emission category (e.g. passenger car diesel, <1500ccm, EURO 3)

$$\text{total mileage}_{\mathrm{E_i}} = \sum_{\mathrm{Jg=start.}}^{\mathrm{end}} (\text{stock}_{\mathrm{Jg,year\,i}} \times \text{km/vehicle}_{\mathrm{Jg_i},\mathrm{year\,i}})$$

(4) calculation of the total fuel consumption and emissions of each emission category

$$\text{Emission}_{\mathrm{E_i}} = \text{total mileage}_{\mathrm{E_i}} \times \text{emission factor}_{\mathrm{K_j},E_i}$$

(5) Calculation of the total fuel consumption and emissions of each vehicle category

$$\text{Emission}_{\text{veh.category}} = \sum_{E_i=1}^{end} \text{Emission}_{E_i}$$

(6) Calculation of the total passenger-km and ton-km

$$\text{transport volumes}_{\text{veh.category}} = \sum_{E_i=1}^{end} (\text{vehicle mileage}_{E_i} \times \text{loading}_{E_i})$$

(7) Summation over all vehicle categories

with Jg_i........Index for a vehicle layer (defined size class, propulsion type, year of first registration)

E_i ....Index for vehicles within a emission category (defined size class, propulsion type and exhaust certification level)

The emission factors for all vehicle emission categories are defined for urban, road and motorway. For HDV the influence of the vehicle loading is taken into consideration by simulating the necessary propulsion work of the engine together with emission factors based on [g/kWh] basis. Cold start and evaporative emissions are simulated in detail as function of vehicle emission category, ambient temperature, parking time and trip length after the start of the engine. Emission factors are based on a representative number of vehicles and engines measured in real world driving situations and are compatible to the HBEFA 2.1 (Keller, 2004). The model thus includes all information for the simulation of different scenarios in the traffic sector while the model design allows an fast and efficient working by using modular systems of input files. The total set of input data can not be described here in detail. The main model parameters used for HDV in the baseline scenario are given in the following list.

	Basic emiss.	CO	NO_x	HC	PM
	[g/kWh]				
EURO I	282.50	2.750	8.300	1.090	0.523
EURO II	263.83	1.820	8.650	0.580	0.182
EURO III	279.52	2.490	7.300	0.710	0.310
EURO IV	268.34	1.460	5.500	0.630	0.055
EURO V	266.10	1.480	2.500	0.640	0.055
EURO VI	273.93	0.600	0.560	0.448	0.025

Table 81 Basic emission factors used for HDV. Depending on the actual load in the driving cycle the factors are corrected with characteristic lines (see e.g. Figure 10).

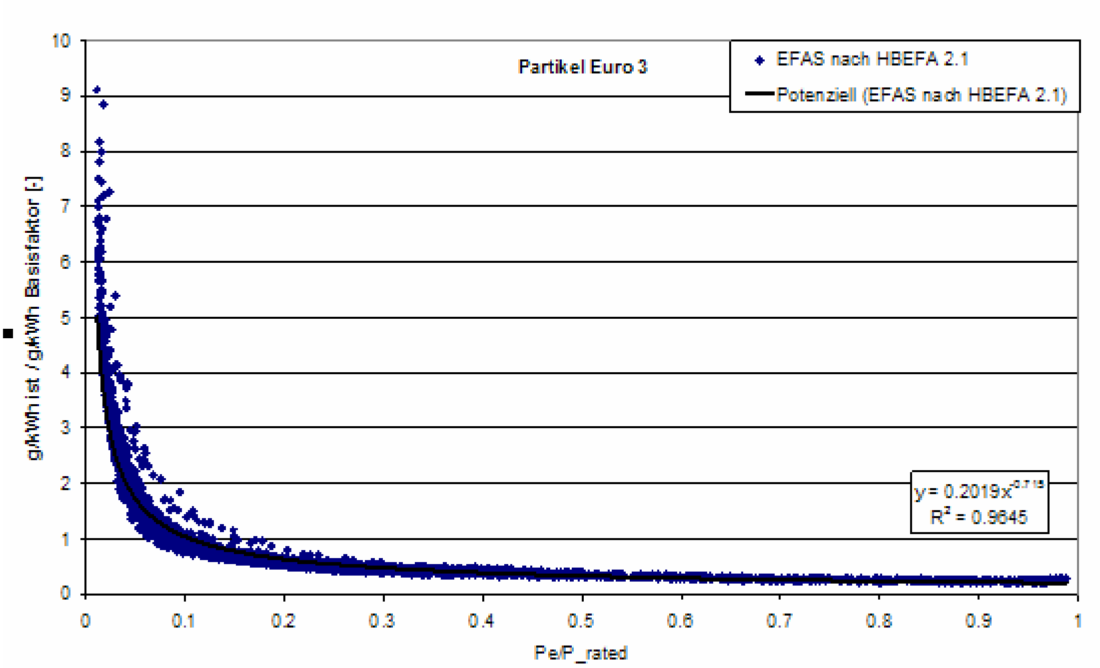


Figure 45 Example for the characteristic lines used for the simulation of HDV emissions to define emission levels as function of the actual engine power used in a driving cycle

C	Solo trucks 3.5-15t			Solo trucks >15t			Truck trailers+semi trailers		
Year	m_{max}	m_{veh}	LF	m_{max}	m_{veh}	LF	m_{max}	m_{veh}	LF
	[kg]	[kg]	-	[kg]	[kg]	-	[kg]	[kg]	-
2000	9956	5241	0.410	21509	10345	0.310	35973	14089	0.600
2001	9970	5253	0.410	21661	10399	0.310	36127	14130	0.600
2002	10001	5276	0.410	21795	10447	0.310	36213	14152	0.600
2003	10008	5282	0.410	21912	10489	0.310	36355	14190	0.600
2004	10066	5322	0.410	22093	10554	0.310	36533	14237	0.600
2005	10078	5329	0.410	22237	10623	0.310	36725	14312	0.600
2006	10091	5335	0.410	22383	10692	0.310	36918	14387	0.600
2007	10103	5342	0.410	22529	10762	0.310	37112	14463	0.600
2008	10116	5349	0.410	22676	10832	0.310	37307	14539	0.600
2009	10128	5355	0.410	22824	10903	0.310	37503	14615	0.600
2010	10141	5362	0.410	22973	10974	0.310	37700	14692	0.600
2011	10154	5369	0.410	23124	11046	0.310	37898	14769	0.600
2012	10166	5375	0.410	23275	11118	0.310	38097	14847	0.600

Table 82 Vehicle size classes and corresponding maximum gross vehicle masses (mmax), vehicle empty mass (mveh) and load factors (LF). LF include empty running also.

The vehicle stock and the vehicle mileage were adapted to meet the overall numbers in the basic scenario defined in this study. The share of the single HDV categories in the total HDV mileage was used as for Austria since the data is very similar for Germany and Switzerland (for other countries no detailed data from reliable sources was obtained within the short project duration).

	GLOBEMI	GE+AUT+CH
rigid truck	24%	29.0%
truck-+ semitrailer	64%	67.9%
garbage truck		0.4%
bus + coaches	12%	2.7% (bus only)
Total	100%	100.0%

Table 83 Share of HDV categories in the overall mileage assumed here for EU 25 (GLOBEMI) compared to the total for Germany, Austria and Switzerland.

The model Phem

The model Phem (Passenger car and Heavy duty vehicle Emission Model) has been developed in several international and national projects, namely the EU 5th research framework program ARTEMIS, the COST 346 initiative and the German-Austrian-Swiss cooperation on the Handbook of Emission Factors (Hausberger, 2002). The model and the validation is published in several journals and conference proceedings.

For a given driving cycle, which is defined by course of vehicle speed and road gradient (change of altitude per horizontal traveled distance), PHEM calculates the necessary engine power second per second according to the driving resistances and losses in the transmission system. The actual engine speed is simulated by the transmission ratios and a driver's gear shift model. The actual emission level is then interpolated from engine emission maps. To take transient influences on the emission level into consideration the results from the steady state emission map are corrected by using transient correction functions. Based on detailed measurements on 82 HDV engines average engine emission maps for the engine certification levels EURO 0 to EURO 5 have been elaborated. Also a data set on the relevant vehicle characteristics of EURO 0 to EURO 5 HDV have been defined, where each EURO-category is separated into HDV-classes according to vehicle type, maximum allowed gross weight and vehicle loading factor (vehicle loading divided by maximum allowed vehicle loading). This data set allows the detailed simulation of HDV fleet emissions for any traffic situation with a high accuracy. The model is applied also for passenger cars, using a similar method (Hausberger, 2003). A scheme of the model is shown in Figure .

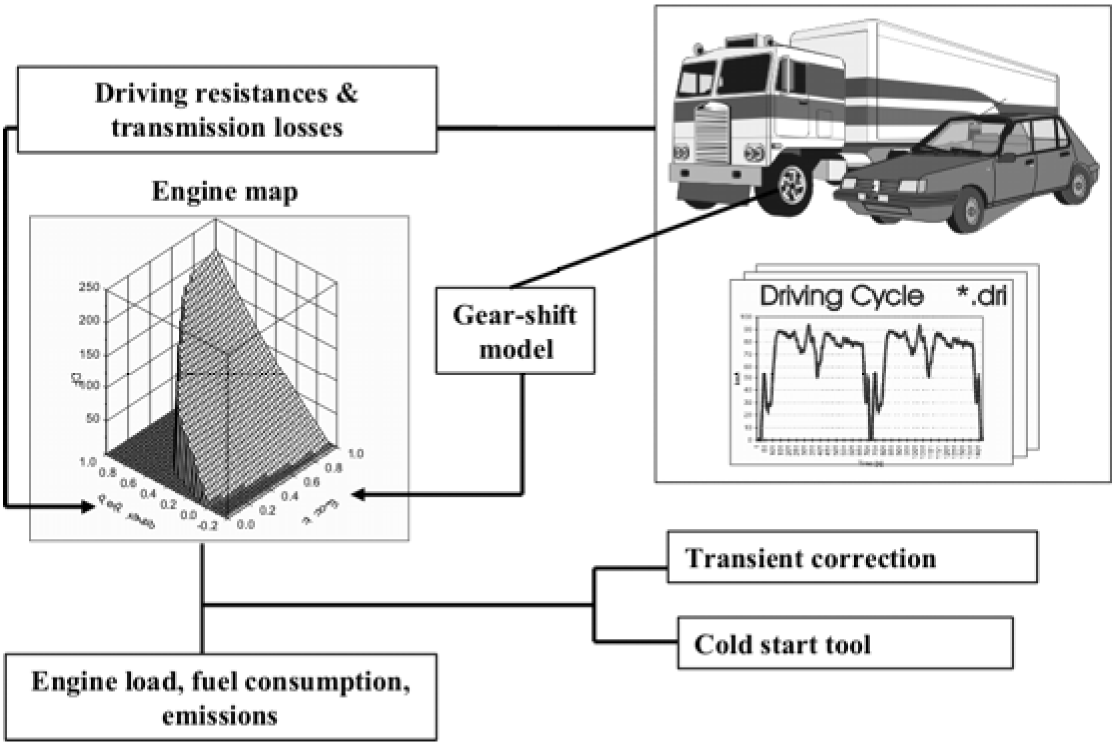


Figure 46 Schematic picture of the model Phem.

ANNEX TO CHAPTER 6.3: ALL POLICIES AND MEASURES SORTED BY MARGINAL ABATEMENT COST

Measure	Sector	Em. red. [Mtonnes CO_{2eq}]	MAC [Euro/ton CO_{2eq}]	Accumul. em. red. [Mtonnes CO_{2eq}]
Application of continuous casting	Industry	0.0	-279	0.0
Energy efficient TV and video equipment	Household	0.4	-235	0.4
Very energy efficient refrigerators and freezers	Household	0.0	-227	0.4
Efficient lightning: Best Practice (partly implemented)	Household	0.0	-219	0.4
Freight logistic optimisation	Freight	4.7	-219	5.1
Efficient lightning: Best Practice (fully implemented)	Household	0.5	-216	5.5
Efficient office equipment: Best Practice	Services	0.0	-216	5.5
Building Energy Management Systems (BEMS): electricity	Services	0.0	-216	5.5
Efficient space cooling equipment	Services	0.1	-208	5.7
Miscellaneous options (cheap tranche)	Household	0.0	-200	5.7
Efficient lighting: Best Practice level 1	Services	0.2	-193	5.9
Miscellaneous options (moderate costs tranche)	Household	2.6	-189	8.5
Very efficient lighting: Best Practice level 2	Services	0.2	-175	8.7
Building Energy Management Systems (BEMS): space heating and cooling	Services	7.7	-156	16.4
Increased weight limit (44t)	Freight	5.9	-97	22.3
Improved process control	Industry	0.0	-92	22.3
Miscellaneous	Industry	0.0	-91	22.3
Debottlenecking	Industry	0.0	-91	22.3
Miscellaneous I (Low cost tranche)	Industry	0.0	-81	22.3
Refineries: Reflux overhead vapour recompression (distillation)	Energy supply	3.0	-80	25.3
Micellaneous II (High cost tranche)	Industry	0.0	-70	25.3
Efficient refrigerators and freezers: Best Practice	Household	1.1	-69	26.4
Proces s integration. e.g. by applying pinch technology	Industry	0.0	-68	26.4
Ceramics - new capacity	Industry	0.0	-65	26.4
Miscellaneous I (Low cost tranche)	Industry	3.4	-64	29.8
Refineries: Power recovery (e.g. at fluid catalytic cracker)	Energy supply	0.5	-62	30.3
Electricity savings	Industry	0.0	-61	30.3
F ractionation - various options	Industry	0.1	-61	30.4
Miscellaneous I (Low cost tranche)	Industry	4.8	-59	35.1
Food. beverages and tobacco - micellaneuous I (Low cos t tranche)	Industry	2.5	-59	37.6
Increased weight limit (60t)	Freight	8.8	-58	46.4
Miscellaneous	Industry	1.4	-57	47.8

Measure	Sector	Em. red. [Mtonnes CO_{2eq}]	MAC [Euro/ton CO_{2eq}]	Accumul. em. red. [Mtonnes CO_{2eq}]
Glass - new capacity	Industry	0.1	-55	47.9
Miscelleneous - building materials	Industry	0.8	-53	48.6
Raising cullet percentage in raw material	Industry	0.1	-53	48.7
Paper - New capacity	Industry	1.0	-52	49.7
Retrofit houses: wall insulation	Household	13.3	-51	63.1
Electricity savings	Industry	0.1	-47	63.2
Cement - new capacity	Industry	0.6	-46	63.8
Process integration. e.g. by applying pinch technology	Industry	0.0	-45	63.8
Food, beverages and tobacco - micellaneuous II (High cost tranche)	Industry	3.5	-42	67.3
Miscellaneous I (Low cost tranche)	Industry	1.8	-42	69.1
Landfill diversion:Paper recycling	waste	0.5	-42	69.6
Biomass (waste) 1b: CHP on solid biomass	Energy supply	2.0	-41	71.6
Reduce clinker content of cement	Industry	0.1	-41	71.7
Improving wet process kilns	Industry	0.3	-41	72.0
Use of waste derived fuels	Industry	0.4	-40	72.4
Optimisation of heat recovery of clinker cooler	Industry	0.1	-38	72.5
Pulverised coal injection up to 30% in the blast furnace (primary steel)	Industry	0.4	-36	72.9
Biomass (waste) 3b: Heat only on solid biomass	Energy supply	12.7	-36	85.6
Refineries: Miscellaneous I (Low cost tranche)	Energy supply	3.0	-35	88.6
Retrofit houses: roof insulation	Household	9.3	-35	97.9
Efficient CO_2 separation (e.g. by using membranes)	Industry	0.0	-35	97.9
Improved drying, e.g. condensing belt drying	Industry	0.4	-34	98.3
Engine improvements	Freight	0.5	-33	98.8
Retrofit services buildings: wall insulation	Services	2.6	-32	101.3
Miscellaneous II (High cost tranche)	Industry	4.1	-32	105.5
Fuel efficient driving	Passenger	4.0	-31	109.4
Cracking furnace - variuous options	Industry	0.1	-28	109.5
Miscellaneous II (High cost tranche)	Industry	13.5	-27	123.0
Tyre pressure monitoring systems	Passenger	2.0	-20	125.0
Landfill: Heat production Waste	waste	0.5	-19	125.5
Reduction of average TA CO_2 emission by 15 g/km	van	0.5	-16	125.9
Miscellaneous	Industry	1.0	-15	126.9
New energy efficient residential houses: (Best practice)	Household	2.1	-13	129.1
Other non-ferro metals - miscellaneuous	Industry	2.5	-13	131.6
Batch and cullet preheating	Industry	0.3	-13	131.8
Miscellaneous II (High cost tranche)	Industry	8.3	-13	140.1

Measure	Sector	Em. red. [Mtonnes CO_{2eq}]	MAC [Euro/ton CO_{2eq}]	Accumul. em. red. [Mtonnes CO_{2eq}]
Application of multi-stage preheaters and pre-calciners	Industry	0.1	-12	140.1
Pressing to higher consistency, e.g. by extended nip press (paper making)	Industry	1.3	-11	141.4
Industrial refrigeration: hydrocarbons and NH_3	Industry	0.3	-11	141.6
Retrofit services buildings: roof insulation	Services	2.4	-10	144.0
Application of efficient evaporation processes (dairy)	Industry	0.3	-10	144.3
Reduced air requirements, e.g. by humidity control in paper machine drying hoods	Industry	1.5	-7	145.8
Driver training at HDV	Freight	2.9	-5	148.7
Various improvements of compressors Compressors	Fossil fuel extraction	0.2	-5	148.9
Inspection and maintenance - power equipment Energy requirements	Fossil fuel extraction	0.1	-5	149.0
Reduced rolling resistance	Freight	9.0	-3	157.9
Aliminium: Side worked pre-baked anode cell (SWPB) conversion	Industry	1.3	-2	159.2
Landfill: Electricity generation Waste	waste	2.5	-2	161.7
Increased gas utilisation Process vents/flares	Fossil fuel extraction	0.1	-1	161.8
Coal mining degasification (low and medium recovery rate) Coal mining	Fossil fuel extraction	3.1	-1	164.8
Refineries: Improved catalysts (catalytic reforming)	Energy supply	2.0	0	166.9
Integrated mills - new capacity	Industry	0.6	0	167.5
Scrap preheating in electric arc furnaces (secondary steel)	Industry	0.1	0	167.6
Oxygen en fuel injection in electric arc furnaces (secondary steel)	Industry	0.2	0	167.7
Minimills - new capacity	Industry	2.8	0	170.6
Replacement of mercury and diaphragm processes by membrane electrolysis (chlorine)	Industry	1.1	0	171.7
Semiconductors : etch - alternative chemicals	Industry	0.8	0	172.4
Landfill: Upgrade to SNG (synthetic natural gas) Waste	waste	0.0	0	172.4
Coal mining degasification (medium recovery rate) Coal mining	Fossil fuel extraction	1.0	0	173.5
Industrial processes Adipic acid	Industry	0.0	0	173.5
Oxidation of HFC-23	Industry	5.3	0	178.7
Magnesium production: use of SO2 as protection gas	Industry	2.3	0	181.0
Industrial processes Nitric acid	Industry	16.5	0	197.5
Foam PU-one component: hydrocarbons	Industry	2.3	0	199.7
Coal mining abatement from ventilation air Coal mining	Fossil fuel extraction	0.3	1	200.0
Aluminium: Vertical stud Soderberg	Industry	0.2	1	200.2

Measure	Sector	Em. red. [Mtonnes CO$_{2eq}$]	MAC [Euro/ton CO$_{2eq}$]	Accumul. em. red. [Mtonnes CO$_{2eq}$]
anode (VSS) retrofit				
Landfill: Flaring Waste	waste	3.0	1	203.3
Reducing flaring/venting emissions related to associated gas Associated gas	Fossil fuel extraction	0.1	2	203.4
Miscellaneous I (Low cost tranche)	Industry	9.8	2	213.1
Refiner improvements	Industry	0.8	2	213.9
Foam PU-pipe in pipe: pentane	Industry	0.1	2	214.0
SF6 Recovery from gas insulated switchgears	Energy supply	0.5	4	214.5
N2O Combustion processes fluidised bed after burner	Energy supply	0.5	4	215.0
Domestic refrigeration: hydrocarbons	Household	0.4	4	215.4
Industrial food refrig.: hydrocarbons and NH3	Industry	1.5	4	216.9
N2O Combustion processes fluidised bed reversed air staging	Energy supply	0.5	5	217.4
Improved melting technique and furnace design	Industry	0.8	5	218.2
Low pressure ammonia synthesis	Industry	0.0	6	218.2
Fertilisers - new capacity	Industry	0.2	6	218.4
Landfill: Increased oxidation Waste	waste	5.5	6	223.9
Wind energy - onshore	Energy supply	15.2	7	239.2
Foams XPS : carbon dioxide	Industry	4.5	7	243.7
Efficient washing machines, clothes dryers, dish washers: Best Practice	Household	0.2	8	243.9
Biomass (cultivated) 3a: Heat only on solid biomass	Energy supply	32.5	9	276.4
Utilisation of process vents and other options Various oil and gas	Fossil fuel extraction	0.1	12	276.5
Retrofit houses: (highly) insulated windows	Household	5.8	12	282.3
Aerosols: hydrocarbons	Industry	1.5	12	283.8
Gas turbine integration	Industry	0.2	13	284.0
NGCC	Energy supply	127.0	16	411.0
Landfill diversion: Anaerobic digestion (1) Waste	waste	0.5	18	411.5
Foam PU-spray: water	Industry	0.8	22	412.3
Foam PU-flexible faced laminate: pentane	Industry	0.8	25	413.0
Offshore flaring instead of venting of process vents Process vents/flares	Fossil fuel extraction	0.1	26	413.1
Large hydropower	Energy supply	7.6	27	420.7
Biomass 2: CHP anaerobic digestion	Energy supply	2.0	27	422.7
Leak reduction Refrigeration HDV	Freight	0.7	29	423.4
Foam PU-discontinuous panels : pentane	Industry	0.8	33	424.1

Measure	Sector	Em. red. [Mtonnes CO_{2eq}]	MAC [Euro/ton CO_{2eq}]	Accumul. em. red. [Mtonnes CO_{2eq}]
Foam PU-blocks : pentane	Industry	0.8	33	424.9
Semiconductors: Chemical vapour deposition (CVD), NF3	Industry	7.5	34	432.4
Landfill diversion: Incineration (1) Waste	waste	3.5	35	435.9
Small hydropower	Energy supply	1.0	36	436.9
Heat recovery in TMP	Industry	5.7	38	442.6
Foam PU-continuous panels: pentane	Industry	0.2	39	442.7
Thin slab casting techniques	Industry	0.8	40	443.5
Retrofit services buildings: (highly) insulated windows	Services	5.7	42	449.2
Replacement grey cast iron network low Fugitive emissions	Fossil fuel extraction	5.1	44	454.3
Recovery of process gas from coke ovens. blast furnaces and basic oxygen furnaces (primary steel)	Industry	0.8	44	455.1
Stationary air conditioning DX (distributed technology): leak reduction	Services	0.2	45	455.3
Biomass (cultivated) energy 1a: CHP on solid biomass	Energy supply	14.7	48	470.1
Manure: slowing down anaerobic decomposition	Agriculture	1.0	60	471.0
Stationary air conditioning chiller: HC and NH_3	Services	0.2	51	471.2
Air resistance Freight	Freight	2.4	56	473.6
Miscellaneous II (High cost tranche)	Industry	8.9	57	482.6
Commercial refrigeration: leakage reduction	Services	0.4	59	482.9
Landfill diversion: Composting (1) Waste	waste	0.5	59	483.4
CO_2 removal and storage	Energy supply	25.4	61	508.8
Advanced heating systems: condensing boilers	Household	2.7	61	511.5
Enteric fermentation: propionate precursors - dairy	Agriculture	0.4	74	511.9
Geothermal electricity production	Energy supply	1.0	64	512.9
Fuel efficient airco systems	Passenger	0.5	66	513.4
Geothermal heat production	Household	0.0	70	513.5
Refineries: Miscellaneous II (High cost tranche)	Energy supply	3.0	73	516.5
Foam PU-appliances : pentane	Industry	0.2	76	516.7
Landfill diversion: Composting (2) Waste	waste	0.3	76	516.9
Advanced reforming	Industry	0.1	79	517.0
Wind energy - offshore	Energy supply	9.1	85	526.1
New very energy efficient residential houses: Zero Energy	Household	0.5	86	526.7

Measure	Sector	Em. red. [Mtonnes CO_{2eq}]	MAC [Euro/ton CO_{2eq}]	Accumul. em. red. [Mtonnes CO_{2eq}]
Retrofit exis ting Hall-Héroult proces s (e.g. alumina point-feeding, computer control)	Industry	0.4	87	527.1
Increas ing the pipeline examination frequency Fugitive emissions	Fossil fuel extraction	2.0	93	529.1
S emiconductors : etch - oxidation	Industry	2.3	96	531.4
Landfill diversion: mechanical-biological pretreatment (MBT) Was te	waste	2.6	96	534.0
Replacement grey cast iron network high Fugitive emissions	Fossil fuel extraction	5.1	97	539.1
Reduction of average TA CO_2 emission by 30 g/km	van	0.5	98	539.7
Various options: compressors, associated gas, system upsets Various oil and gas	Fossil fuel extraction	0.2	100	539.9
Low rolling resistance tyres	Passenger	4.4	109	544.3
Landfill diversion: Anaerobic diges tion (2) Was te	waste	0.3	113	544.6
Enteric fermentation: proprionate precursors - non dairy	Agriculture	0.1	116	539.3
Landfill diversion: Incineration (2) Was te	waste	1.9	120	546.4
Tidal energy	Energy supply	1.0	143	547.5
Reduction of average TA CO_2 emission from 140 to 135 g/km	Passenger	1.0	146	548.5
Low viscosity lubricants	Passenger	9.4	150	557.9
diesel hybrids in city buses	Freight	0.4	153	558.3
E fficient production of low-temperature heat (heat recovery from hightemperature processes)	Industry	1.8	164	560.0
Biofuels (1.7% additional use)	Passenger	5.9	169	565.9
CHP	Energy supply	31.5	170	597.4
Biofuels (1% additional use)	van	0.4	177	597.8
New energy efficient services buildings: Energy efficiency level 1	Services	2.2	177	600.0
Reduction of average TA CO_2 emission from 135 to 130 g/km	Passenger	1.3	187	601.3
Specific long distance vehicles	Freight	2.5	226	603.8
Reduction of average TA CO_2 emission from 130 to 125 g/km	Passenger	1.3	233	605.0
Reduction of average TA CO_2 emission by 45 g/km	van	0.5	243	605.5
Reduction of average TA CO_2 emission from 125 to 120 g/km	Passenger	1.3	283	606.7
CNG	Passenger	1.1	312	607.9
Solar thermal	Household	1.9	330	609.8
Solar power: photovoltaic energy	Energy supply	0.5	373	610.3
New very energy efficient services build-	Services	1.5	378	611.7

Measure	Sector	Em. red. [Mtonnes CO_{2eq}]	MAC [Euro/ton CO_{2eq}]	Accumul. em. red. [Mtonnes CO_{2eq}]
ings: Energy efficiency level 2				
Wettable cathode	Industry	0.4	398	612.1
Reduction of average TA CO_2 emission by 60 g/km	van	0.5	409	612.5
Bio Diesel	Freight	5.6	495	618.2
Advanced heating systems: heat pumps	Household	3.8	524	622.0
Biomass 4b: biodiesel	Energy supply	12.2	544	634.2
Biomass 4a: ethanol	Energy supply	4.6	665	638.7
Lightweight construction	Freight	5.7	859	644.4