SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

SUSTAINABILITY ASSESSMENT OF TECHNOLOGIES AND MODES IN THE TRANSPORT SECTOR IN BELGIUM (SUSATRANS)

I. DE VLIEGER, S. PROOST

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PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS → TRANSPORT

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SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT
POLICY (SPSD II)

Part 1:
Sustainable production and consumption patterns

FINAL REPORT

SUSTAINABILITY ASSESSMENT OF TECHNOLOGIES AND MODES IN THE TRANSPORT SECTOR IN BELGIUM (SUSATRANS)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Context

From 1990 to 2003 the number of vehicle kilometres driven on Belgian roads has increased by 32 % [1]. Freight and passenger transport is expected to grow further in the coming years.

From 1990 to 2002 EU-15 greenhouse gas emissions from transport (international aviation and navigation excluded) have increased by nearly 22 %. If no additional measures are taken, emissions will increase further by about 12 % in 2010. In 2002 the contribution of transport in the total EU-15 greenhouse gas emissions was 21 %. In Belgium this fraction is 17 % [2]. The rise of greenhouse gas emissions from transport makes it difficult to meet the overall objective set by the Kyoto Protocol (Belgian reduction of greenhouse gases by 7,5 % in 2010 compared to 1990).

Besides greenhouse gases, emissions of nitrogen oxides (NO_x), volatile organic compounds (VOC) and particulate matter (PM) are of concern. In Belgium, transport contributes about 46 % to the total NO_x emissions, 22 % to the total non-methane VOC (NMVOC) and 34 % to the total PM2.5 emissions.

Potential solutions for the environmental problems associated with transport are the introduction of cleaner and alternative vehicles and the shift of traffic to cleaner transport modes. In this report the sustainability of these alternatives is analysed.

1.2 Objectives

Within the SUSATRANS project we wanted to gain insight in the sustainability of policy measures that affect introduction of new technologies in the transport sector and the shift between road transport and other modes. SUSATRANS is the acronym for "Sustainability assessment of technologies and modes in the transport sector in Belgium", being the initial name of the project.

We defined the following sub-objectives:
- Performing an overall technological, social, economical and environmental evaluation of individual technologies and measures.
- Obtaining a better understanding of consumer behaviour with regard to new technologies.
- Updating and developing models to evaluate the impact of policy measures on mobility demand, emissions and external costs of transport.
- Delivering recommendations to national, regional and local policies related to mobility and environment.

1.3 Bookmarker

Chapter 2:	This chapter gives a description of the methodologies that were used in this study. We explain the sustainability screening of individual technologies, the TREMOVE transport model, the emission models and the environmental impact assessment methodology "ExternE".
Chapter 3:	Here we present the results of the multiple criteria sustainability evaluation on individual technologies.
Chapter 4:	In this chapter we calculated the emissions and impacts of two scenarios without additional policy measures. I.e. a business-as-usual (BAU) scenario as designed by CES and VITO. We give an indication of the uncertainties in these scenarios.
Chapter 5:	In contrast, this chapter shows the result of scenarios in which additional measures are taken, i.e. the "levelled technology tax" scenario compared to the "combined tax policy" scenario. Besides effects on emissions and impacts, also welfare assessments are done here.
Chapter 6:	We discuss the European directives related to the introduction of biofuels in transport. We describe the necessary policy measures in Belgium that are needed to fulfil the targets proposed in the directives.
Chapter 7:	Here, we present the general conclusions of this study together with the scientific progress made and future work to be done.
Annexes:	Background information on different topics can be found in the annexes.

2 METHODOLOGY

2.1 Project structure

Figure 1 shows the structure of the project and the interaction between the various tasks. Firstly, several new technologies were subject of a sustainability assessment. Based on this assessment VITO selected a number of sustainable transport technologies. Second, CES determined the actual penetration of the selected sustainable technologies and modes, selected policy measures and evaluated the costs for the different stakeholders and the environmental impact for Belgium. Third, VITO performed a rough technology assessment of biofuels in Belgium. Finally, based on this multidisciplinary study, CES and VITO formulated advice to obtain a more sustainable transport policy in the future.

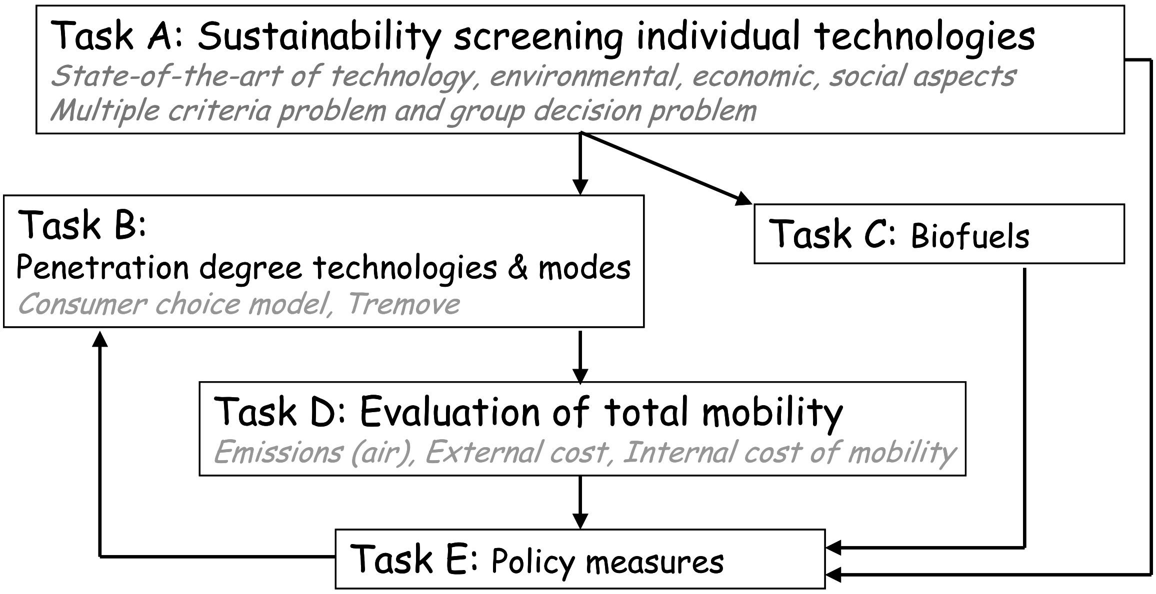

Figure 1: overview of the project structure

2.2 Sustainability screening of individual technologies (Task A)

Within this section we describe the approach of the sustainability evaluation of individual technologies and the selection of technologies to be integrated in the scenarios within Task B and D.

2.2.1 Definition of sustainable technologies

Before starting with the sustainability evaluation, we define what we understand as sustainable technologies.

Several definitions of sustainable technologies exist, however most only take into account ecological aspects, i.e. resources and emissions [3, 4, 5]. We build on the characteristics of sustainable technologies defined by Russel [6]:

- Low environmental impact:
  - very low emissions to the environment in production, use and disposal;
  - no toxic releases;
  - benefit environment indirectly through uses and/or inherent efficiency.

- Resource efficiency:
  - efficient utilization of material resources, often using recycled material;
  - based on renewable resources and energy (or minimal use of non-renewable energy);
  - efficient consumption of energy in production and use;
  - durable, re-usable and/or recyclable.

- Economic advantages:
  - economically cost-effective compared to conventional product or service;
  - incorporate externalities in market price;
  - can be financed by the user through various financial saving streams;
  - improve productivity or competitiveness of industry and commerce.

- Social advantages:
  - enhance or maintain living standards or quality of life;
  - readily available and easily accessible to all income groups and cultures;
  - consistent with themes of decentralization, individual control and democracy.

2.2.2 Evaluation criteria

This section tackles with the evaluation criteria used for the sustainability screening and the way they were selected. As sustainability involves a broad range of criteria and for practical reasons not all criteria can be assessed with the same detail, a selection has to be made.
Besides sustainability criteria in the domains of environment, society and economy, importance was also given to the technological feasibility since an evaluation of a technology was done.

The selection and definition of the criteria for the screening of individual new technologies was a long and intense process involving experts in all major fields of sustainable development and the users committee of the SUSATRANS project. First we ended up with 40 criteria, see Figure 2. No good figures could be found on the criteria related to the cost of infrastructure, neither on the criterion ‘subsidies’ within the fuel cost. So, finally 35 criteria were involved in the sustainability evaluation.

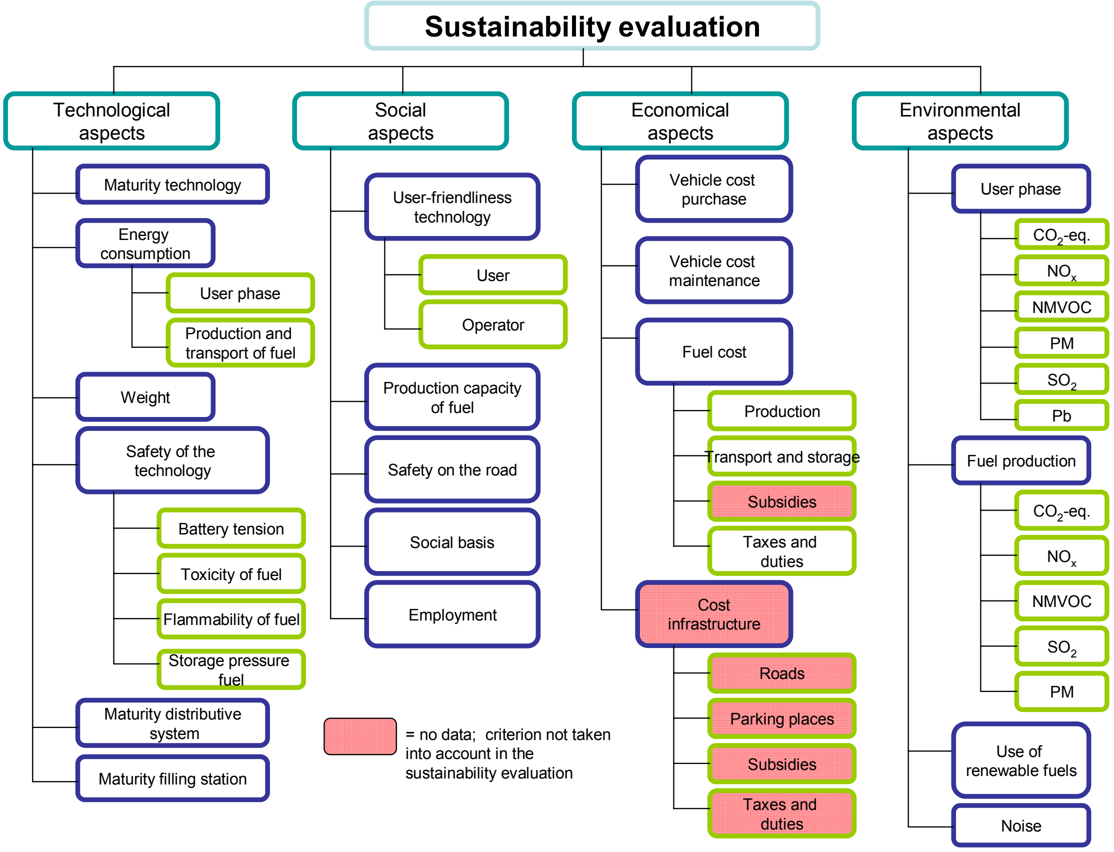

Figure 2: criteria used to perform the sustainability evaluation

We performed an inventory of fuels and engine technologies, which resulted in 42 technological options for light duty vehicles and 39 for heavy duty vehicles. Within the project it was not feasible to perform for all technological options an extensive sustainability evaluation taking into account 35 criteria.

To lower the amount of technologies we carried out a pre-screening taking into account 7 criteria:

- continuity of energy supply;
- dependence of non-renewable resources;
- availability of the fuel;
- additional cost of the technology/fuel according to diesel;
- energy-efficiency (well – to – wheel);
- greenhouse gas emissions during production and user phase;
- PM-emissions in the user phase.

This pre-screening brought the amount of technology options on 15 for light duty vehicles and 10 for heavy duty. More information on the pre-screening can be found in annex I.

For the remaining options we executed an extended sustainability evaluation taking into account the criteria shown in Figure 2. More information on these criteria is given in annex II.

Several criteria were hard to score on an absolute basis, consequently we scored these criteria an ordinal scale. To do so we defined a diesel-fuelled vehicle equipped with the 2000 technology to be the reference technology.

2.2.3 Methodology applied to rank technologies

This section describes briefly the approach used to rank road transport technologies for the years 2000, 2010 and 2020. For this part of the project, we have got methodological support of Mr. Wim De Keyser (SIA, Dendermonde-Belgium). A more theoretical description of the methodology can be found in annex II.

On the one hand we faced three decision problems (light duty vehicles (LDV), heavy duty freight (HDF) and heavy duty persons (HDP)) consisting of multiple alternatives (see Table 12 and Table 13) where multiple criteria (35, see Figure 2) were taken in consideration (with deterministic evaluations for each alternative on each criterion). In fact, the decision problems under consideration were multiple criteria problems.
On the other hand, multiple decision makers were involved in the decision processes, which turned the multiple criteria problems into group decision problems. A Group Decision Support (GDS) can handle such a situation and returns as solution for each decision problem a group's ranking of the alternatives. In short, a GDS uses a multiple criteria method to obtain this ranking.

Based on the amount of data and the required expertise of the decision makers, we decided to handle the four aspects of sustainability (technological, sociological, economical and ecological) separately.

Technologies were ranked for each aspect separately by using the ARGUS multiple criteria method and a Group Decision Support System (GDSS) supported by ARGUS [7,8]. Finally the results of each aspect were aggregated by means of a heuristic method to come to a final ranking of the technologies.

Within the ARGUS multiple criteria analysis the decision makers gave separately their level of importance for the criteria within one or more aspects. Furthermore they expressed preferences, between two values on a criterion, on an ordinal scale. This resulted in rankings of technologies per decision maker and aspect.

For each of the four aspects the rankings of the different decision makers were aggregated to one ranking, known as a GDSS exercise. This was done by treating this problem as a new ARGUS multiple criteria exercise.

Finally the results of the GDSS for each aspect was aggregated by means of a heuristic method to come to a final ranking.

We passed through above steps for three groups of road vehicles: light duty vehicles (passenger cars), heavy duty freight transport (trucks) and heavy duty passenger transport (buses).

27 decision makers were involved in the ARGUS/GDSS exercise and 36 decision makers attributed weights to the four aspects of sustainability. Besides experts of

VITO and the users group, also the scientific staff and last year students at the University of Antwerp were involved. Students and scientific staff from departments like sociology, economy, biology and commercial engineering participated in the exercise.

Through the means of a data analysis weights were assigned to the four aspects (see Table 1). The environmental aspect was somewhat more important than the other three aspects.

Table 1: weights given to the sustainability aspects

Technological	Sociological	Economical	Ecological
9	10	9	12

2.3 TREMOVE model (Task B)

The screening conducted in task A comes up with a broad range of technologies which have the potential for a more sustainable transport activity in a near future. We then need a framework to assess the economic and welfare impact of policy measures aiming at a shift towards the sustainable technologies, e.g. a modal shift. The modelling framework selected to carry out this task is the TREMOVE model.
In a first paragraph we discuss the general structure and the scope of the model. In a second paragraph we focus on the car technology choice model, whereas in a third step we have a closer look at the representation in TREMOVE of the internal cost of mobility.

2.3.1 TREMOVE

In this paragraph we will provide a short introduction on the TREMOVE 1.3 model. Next we identify the different points on which this model has to be enhanced in order to allow for the policy simulations considered in the SUSATRANS project.

2.3.1.1 Original TREMOVE model

The TREMOVE 1.3 model is a partial equilibrium representation of the transport markets developed for the EU Commission under the Auto-Oil II Program [9].
The model (see Figure 3) represents all the transport markets (passenger and freight, all modes (4 types of cars, metro, public bus, rail etc.) and contains a crude representation of congestion and a detailed emission module (TRE-part). The model tracks the evolution of the car stock per vehicle type (MOVE stock-part). The model computes the effects and welfare costs of alternative measures to reduce emissions in the transport sector. These measures include taxation and regulation packages ranging from subsidies to public transport and electronic road pricing to the obligation of installing catalytic converters.

The model version for Auto-Oil II covered the 1990-2020 period for 9 EU countries (not including Belgium). Existing transport flow forecast data are used to calibrate the model for every year.

For a more in-depth discussion of the TREMOVE 1.3 model we refer to European Commission et al. (1999) [10].

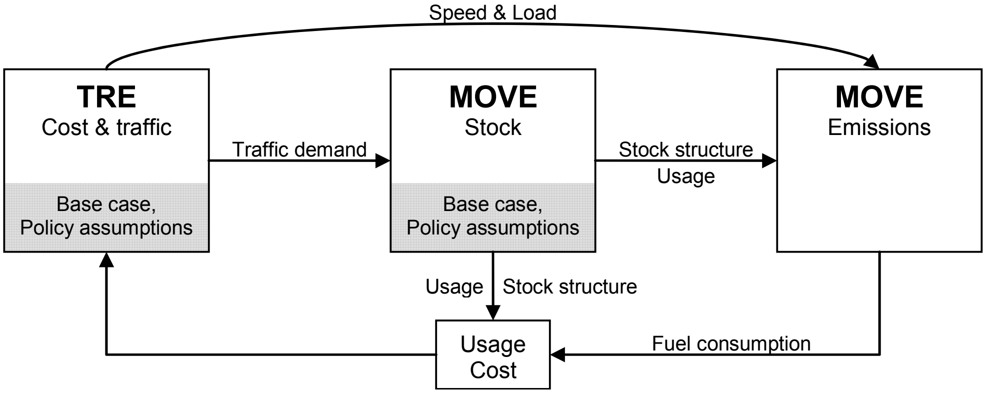

Figure 3: general structure of the TREMOVE model

2.3.1.2 Enhancements of TREMOVE in this SUSATRANS project

We identify several aspects of the model which have to be enhanced in order to allow for a welfare assessment of policy measures addressing sustainability of transport activity. These arise both from the necessity to include more (alternative) technologies as well as the geographical coverage of Belgium that was not included in the Auto-Oil II Program.

The structure of the TRE-part did not need major changes. The only point that had to be considered was the calculation of the internal costs of bus transport activity, as this is only very roughly represented in TREMOVE. This is discussed in paragraph 2.3.3.

We needed to design a consistent transport flow forecast for calibration of the TRE-part. This issue is addressed in paragraph 4.1.1.

For the MOVE stock-part, major rework was necessary in order to extend the scope of the model to include alternative (sustainable) technologies, both for private car and bus activity. The design and estimation of the technology choice model is discussed in paragraph 2.3.2, whereas the construction of a BAU evolution dataset for the technology (and fuel) variables is addressed in paragraph 4.1.2.

To allow for policy measures targeting transport activity emissions, we needed a detailed representation of these emissions. This includes the update of the existing emissions module and the extension to include alternative technologies as well as non-road modes. The MOVE emissions-part was further extended to include an ex-ante emissions calculation required for the calculation of emission taxes in the technology choice model. A brief note on the implementation of the emissions module is provided in paragraph 5.1.1.

2.3.2 Technology choice model

The MOVE vehicle stock part of the TREMOVE model (see Figure 3) includes a vehicle technology choice model that simulates the yearly market shares of the different technologies in new car sales.
The existing choice model only includes conventional technologies for private cars (diesel, gasoline and LPG) and does not include buses at all. In this paragraph we describe the methodology used to design and estimate new choice models both for private cars and buses.

2.3.2.1 Intro

The TRE part of the TREMOVE model (see Figure 3) simulates transport activity for different demand categories. In Figure 4 we provide the transport demand structure for off-peak urban passenger transport.

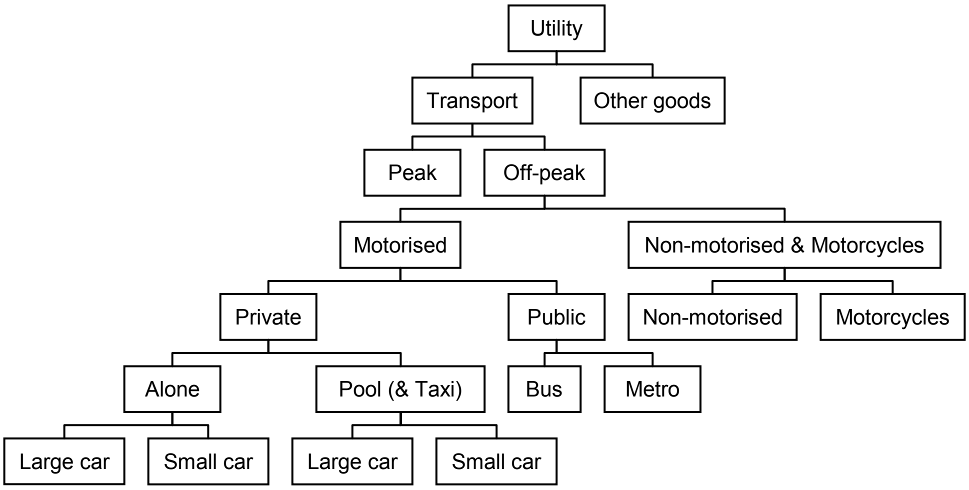

Figure 4: CES utility function structure for off-peak urban passenger transport

The simulated transport activity of the different demand categories is linked to the vehicle technology classes in the MOVE stock module. This link is specified in Table 2.

Table 2: link between transport activity demand and vehicle technology classes

TRE transport demand	*MOVE vehicle technology class*
Motorcycles	Motorcycles & mopeds
Small car	Private cars (<1,4l)
Large car	Private cars (>1,4l)
Bus	Buses
Small trucks	LDF
Big trucks	HDF

The MOVE stock module uses the transport activity data from the TRE-part to calculate for each year and for each vehicle technology class (see Table 2) the desired number of vehicles necessary to meet the transport activity demand level. Based on this desired number of vehicles, the stock of the year before and the number of vehicles scrapped, the level of sales of new vehicles is determined. It is at this point that the technology choice model is applied to determine the market shares of the different technologies for each vehicle technology class.

The car choice models use the levels of the technology variables as input in order to provide technology share data as output. The technology variables can be roughly split in two categories: cost variables and functional variables (e.g. acceleration). A last category of inputs could be related to the consumer (e.g. age), however these variables fall beyond the scope of the TREMOVE model and as such their potential is limited here.

In the initial TREMOVE model, the choice models for the different car technology categories (see Table 2) are limited to conventional technologies, for buses no technology choice model is included. The focus in the SUSATRANS project is mainly on road passenger transport modes as far as the introduction of new technologies is concerned. We therefore designed new choice models for private cars (large and small) and buses. Furthermore, a recalibration of the other technology choice models has been conducted, as well as an update of the base year vehicle stock data (using TRENDS data: see §2.3.2.8).

In a first paragraph we provide a brief introduction on discrete choice theory, the framework which has been used in all the technology choice models.

In the second paragraph we discuss the design and estimation of a stated preference technology choice model that includes alternative technologies as well as an extended range of functional technology variables. The third paragraph describes the estimation of a model including different engine sizes of conventional private car technologies and its estimation based on revealed preference data. Both the stated preference and revealed preference models are integrated in order to get the full private car technology choice model.

The fourth paragraph describes the design of a bus technology choice model which uses a different approach compared to the private car models. In the fifth paragraph we show how we recalibrated the existing choice models of the other technology categories and finally a short note is provided on base year stock data and the update of the scrapping parameters.

2.3.2.2 Discrete choice

Discrete choice theory describes the behaviour of a consumer facing a discrete choice situation such as the purchase of a new car. It is this framework that we will use for the different car technology models.

Discrete choice theory provides a broad range of mathematical modelling frameworks. An extended in depth discussion on discrete choice theory can be found in Ben-Akiva and Lerman (1985) [11], Train (1990) [12], Anderson et al. (1992) [13] and Train (2003) [14].

The consumer who considers the purchase of a vehicle faces a discrete choice situation: he wants to buy a vehicle, and will buy only one unit. To model the behaviour in such circumstances, discrete choice theory offers several models based on random utility theory.

In these models, the probability that a consumer chooses a given alternative depends on the utility of the alternative as well as the utility of all the others on the market. This utility of alternative j as obtained by decision maker n consists of a deterministic and a random term. It is assumed that the consumer will prefer the alternative with the highest utility over the others (utility maximization).

$U_{nj} = V_{nj} + \varepsilon_{nj}$
where:

- V_{nj}: the deterministic part of the utility
- ε_{nj}: the random term

The deterministic term V_{nj} can be function both of attributes of the good and the consumer. It is the part of U_{nj} captured by the researcher.
The random term ε_{nj} accounts for all kind of influences which appear to be random and which make it impossible to observe the choice as a deterministic process. The underlying interpretation is that some characteristics are unobserved are unobservable (for the researcher), and the random term accounts for their influence on U_{nj}. Depending on assumptions on the statistical distribution of the random term εnj, different models are distinguished (e.g. multinomial logit, nested logit, etc.).
The probability that the consumer chooses alternative j is then the probability that the utility U_{jn} is bigger than the utility of all other alternatives U_{in} $i \neq j$. The market shares are then equal to the choice probabilities of the alternatives.
In the technology choice models we use the multinomial and nested logit specifications.

To specify and estimate the car choice model we will combine two techniques: a stated preference approach and a revealed preference approach.
The stated preference approach consists of relying on surveys that reveal choices on hypothetical questions. This technique is the only available technique to study the preferences for new technologies.
The revealed preference approach consists in relying on observable real choices of consumers. This technique is used to specify the choices within the existing technologies: diesel versus gasoline and small versus large cars.

2.3.2.3 Private cars: stated preference approach

The first step in the design of a new private car technology choice model is the specification of a stated preference model which focuses on the choice between different conventional and alternative technologies. In this paragraph we describe the methodology used for the data collection through a survey and the model estimation. In the next paragraph we describe how this model is integrated with a conventional technology revealed preference model in order to cover the full scope of the private car technologies we consider in TREMOVE.

a) Survey

As a first step in preparing the survey we conducted a literature review. Similar surveys have been held in California (Bunch et al. 1993 [15], Brownstone et al. 1996 [16], Brownstone and Train 1999 [17], Brownstone et al. 2000 [18]), Montreal (Ewing and Sarigöllü 1998 [19]), Norway (Ramjerdi et al. 1996 [20], Ramjerdi and Rand 1999 [21]) and the UK (Knight 2001 [22] and Batley et al. 2003 [23]). The approach used in past research was considered to be appropriate for a new survey. However some updates were necessary in order to match the requirements of the SUSATRANS project as well as the framework of the TREMOVE model, e.g. the inclusion of hybrid cars.

- 1st phase: design

  The first phase of the survey consisted of a focus group which was held in Antwerp in spring 2004 and was attended by seven participants. The focus group was used to collect information for the qualitative approach of the survey: identifying the variables considered upon purchase of a new car, how people quantify these variables, in how far they are familiar with new technologies and how they would consider their purchase when available. At the end of the focus group a preliminary design of the survey (based on literature review) was tested in order to identify the number of alternatives to include in the choice sets (see further) as well as difficulties in the survey setup.

- 2nd phase: pre-test

  The second phase of the survey was a small test phase (19 respondents) where the whole survey setup was tested. The main result of the test phase was the further refinement of the quality control.

- 3rd phase: survey

  The final phase was the full survey. In a first step, 257 respondents were selected through a stratified random draw, contacted by CATI[1] and asked to participate in the survey. At the same time, socio-demographic data of the respondent were collected. A second step was to send six choice sets to each respondent. The choice sets contain five choice alternatives each: cars running on diesel, gasoline, LPG and alternative fuel[2] and a fifth car powered either by batteries or by fuel cells. The alternatives were specified to differ only in some variables (see Table 5) for which different levels were proposed. The levels of the variables entering the choice sets were fixed according to a main effects orthogonal fractional factorial plan[3]. The purchase cost variable was further customized based on information collected in the first step.

  In a third step, the respondents were contacted by CATI one more time in order to collect their preferred choice from each set. 209 respondents completed this last part of the survey.

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[1] Computer Assisted Telephone Interviewing

[2] We decided not to further specify the alternative fuel in the survey, based on focus group observations indicating that respondents are not likely to distinguish between non-conventional fuels.

[3] In a main effects orthogonal factorial plan, the combinations of the levels of the different variables in the choice sets is chosen in order to limit as much as possible the number of combinations (or choice sets) needed to estimate the coefficients of the variables (main effects only, so no interaction effects) without introducing correlation between the variables. For a more elaborate discussion of the topic we refer to Day (1995).

b) Model specification and estimation results

Based on the survey results, different specifications for both multinomial and nested logit models were estimated by maximizing the log-likelihood (see Table 3).

Table 3: coefficients of Stated Preference private car technology choice model

Variable Description	Unit	*SP multinomial logit* Coefficient	P [4]	*SP nested logit* Coefficient	P
Lifetime cost	€/vkm	-7,483417	0	-5,399	0
Available luggage space	100%	0,9921	0	0,7443	0
Emissions	100%	-0,8635	0	-0,5624	0,001
Range	100 km	0,2624	0	0,2081	0
Diesel	dummy	0,4621	0	0,2902	0
LPG	dummy	-0,8231	0	-0,4378	0,003
Alternative fuel	dummy	-0,3366532	0,037	-0,1273	0,259
Fuel cell	dummy	-0,1601	0,548	-0,4670	0,030
Battery	dummy	-0,4150	0,122	-0,7206	0,001
Hybrid	dummy	-0,0106	0,887	-0,0126	0,793
Inclusive value[5] non-electric/fuel cell				0,6204	0
Log likelihood		-1767,2477		-1763,3508	

Note that in the survey three cost variables were used (purchase, annual and per kilometre), in the model these have been combined in the lifetime cost variable used in TREMOVE (see also paragraph 2.3.3).

We see that all the generic variables enter the multinomial logit model significantly. The sign of their coefficients is acceptable. Negative signs are observed for all cost variables and emissions, meaning that an increase in the value of these variables decreases the deterministic utility of the choice alternative (see §2.3.2.2). The significance of the emissions coefficient together with the negative sign shows that the respondents of the survey prefer cleaner cars over more polluting ones. This result is in line with earlier studies (e.g. [15]). However, we should remind that we are working in a stated preference setting. Batley et al. [23] raises the issue of respondents who may choose a socially-acceptable alternative rather than what they would buy in a real world setting. Based on focus group findings a formulation for the emissions variable was chosen in order to avoid such associations as much as possible.

For the dummies only the diesel, LPG and alternative fuel differ significantly from zero (at P=5%). This means that we could not measure a significant preference (be it positive of negative) for fuelcell, battery and hybrid cars that is not the result from differences in the values of the generic variables (e.g. purchase cost). For the fuelcell and the battery cars this is not too surprising, as these dummies concern only one choice alternative in half of the choice sets, the amount of information on the influence of these properties is hence limited. The hybrid dummy however is present for four choice alternatives in every choice set, the insignificance is here caused by the very small value of the coefficient estimated, which could not be proven to differ significantly from zero. The hybrid property does clearly not have a significant influence on the choice outcome. This finding is in line with focus group observations.

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[4] P is the probability that the estimated coefficient value does not differ significantly from zero

[5] The inclusive value coefficient is a measure for the correlation in unobserved preferences for the alternatives in the nest.

Also the LPG and alternative fuel dummies have negative coefficients, meaning that these choice alternatives have a lower deterministic utility compared to the gasoline alternative (which has no dummies and serves as reference alternative) when all other properties are equal (purchase cost, emissions, etc.). Diesel has a positive sign, which is not too surprising considering the large share of diesel cars in current sales.

Further specifications of the multinomial logit model have been estimated in order to include squared terms for the generic variables entering the choice sets at three level. However, we could not find any significant influence on the choice behaviour, in contrast to e.g. Ramjerdi [21] and Bunch et al. [15].

In past studies, household income proved to have a significant influence on car technology choice. However, it is also a variable that is very difficult to measure in a survey. To avoid running the risk of failing to measure household income, we made use of a standardized demographic classification by ESOMAR [24]. For each ESOMAR class, the average income is determined based on statistical information by NIS[6]. We have tested different modelling specifications for the income variable, however but no significant influence on purchase behaviour was found. Probably the size of the survey is too small to provide enough choice information. Note that the variance in income is linked to the number of respondents (209).

The next step in model estimation was to change the specification to nested logit. This allows for correlation in non-deterministic utility between different alternatives in the same choice sets.

Estimating the nested logit specification, we tested for several nesting structures but only one was found to result in a significant better modelling structure (χ-square test on log-likelihood): all non-electric/fuel cell alternatives in a nest (see Figure 5).

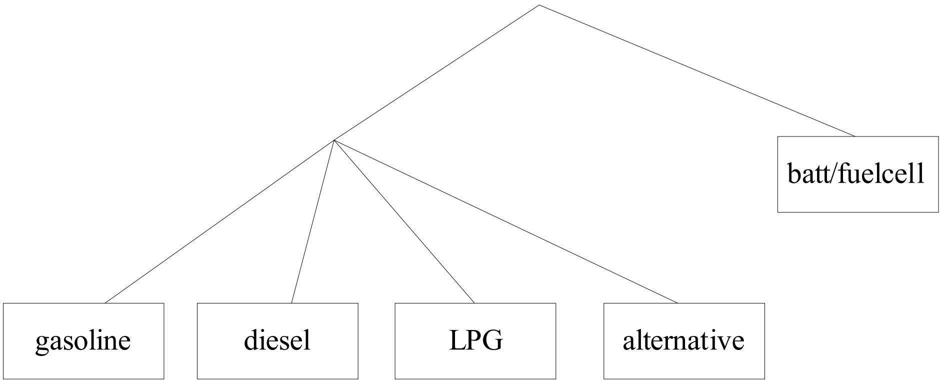

Figure 5: nested structure of SP model based on survey

Comparing our modelling results to past research, we note that the nesting structure identified by Ramjerdi [21] and Bunch et al. [15] is similar to what we observed.

The interpretation of the nested logit model coefficients (Table 3) will not be discussed here, as most conclusions on the significance and signs observed in the multinomial logit model still hold. Only alternative-specific dummies do show some changes, reflecting the change in nesting structure.

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[6] http://statbel.fgov.be

The willingness to pay (WTP) for a change in the value of the different variables can be calculated by dividing the corresponding coefficient by the purchase cost coefficient. The ratio of the coefficients of two variables is a measure for the trade-off that is made by the respondent: the respondent is indifferent to the corresponding changes as the net result on deterministic utility is zero. The resulting WTP is shown in Table 4.

Table 4: WTP in nested logit stated preference private car technology choice model (in 0,01 €/vkm)

Variable Description	Unit	*WTP* €
Lifetime cost	0,01 €/vkm	1
Available luggage space	10%	-1,38
Emissions	10%	1,04
Range	100 km	-3,85
Diesel	dummy	-5,38
LPG	dummy	8,11
Fuel cell	dummy	8,65
Battery	dummy	13,35

For emissions we observe a WTP of 0,0104 €/vkm for a 10 % reduction. For luggage space there is a negative WTP value (or rather a positive willingness to accept) of 0,0138 €/vkm for a decrease in luggage space of 10 %. An increase in range of 100 km is valued at 0,0385 €/vkm.
The dummy coefficients provide rather high WTP estimates. There is clearly major opposition against LPG, which was somewhat expected based on observed discussions in the focus group. It seems that LPG cars still bear the negative image of moving bombs, although the focus group observation indicated that factual information regarding technical safety records of retrofit LPG cars did reach potential buyers. This is confirmed by the insignificance of the willingness to accept for alternative fuel cars: there seems to be no reason to believe that they are more or less explosive than common LPG cars, the only observable difference is the absence of the notorious LPG-label.

A more elaborate description of the survey results and the stated preference approach is provided in annex III.

2.3.2.4 Private cars: revealed preference approach

The stated preference approach used in the paragraph above does provide very useful information on the choice people make facing the fictive situation of choosing between alternative technologies not yet available. However, the resulting model may not reflect actual consumers' behaviour in that the simulated shares may not be in line with actually observed ones. Furthermore, for the emission calculations the "large cars" choice model in TREMOVE (see Table 2) has to include the choice between medium (1,4-2l) and big (+2l) technologies. To overcome both problems, we estimate a separate choice model based on revealed preference information.
The revealed preference model was designed and estimated for the TREMOVE 2 project [25]. Car sales data for the 1999-2000 period covering 17 European countries

were used for model estimation. The sales data were aggregated over quarterly intervals. To keep the resulting model deliberately simple as well as to reproduce the observed shares, average values were used for each of the four technology type categories (medium and big for diesel and gasoline). The resulting dataset contained approx. 150 country-quarter combinations.

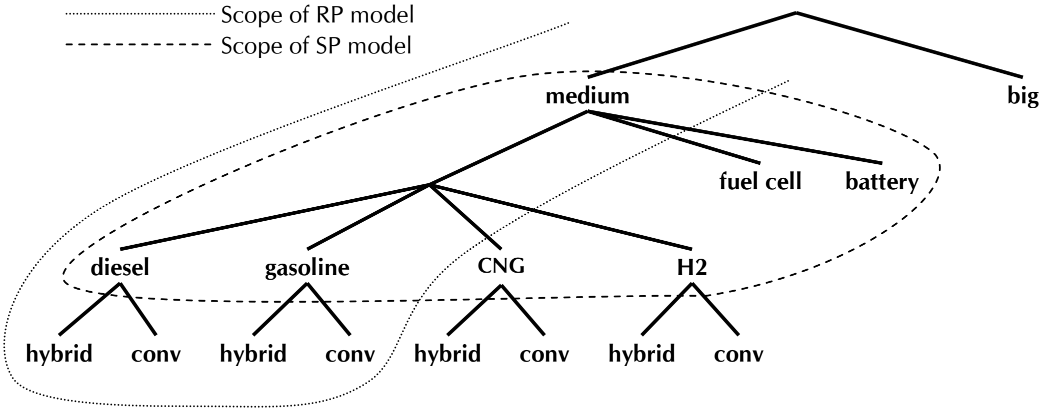

Figure 6: integrated technology choice model structure for large cars

The model is specified as nested logit with nests defined based on fuel type. Estimation was done using actual sales figures as frequency weights. The resulting coefficients are provided in Table 5. In order to add hybrid cars to the model, we added fuel-specific nests containing a conventional and a hybrid alternative for each fuel. The inclusive value coefficient of these fuel-nests has been assumed to be 0,2 (verified by sensitivity analysis). This value is motivated by observations in the focus group, finding that people do not consider hybrid cars as a different technology but rather a new property for existing technologies.
The share of LPG cars has been fixed exogenously at 1% of the gasoline car stock.

2.3.2.5 Private cars: integration of revealed and stated preference

A last step is to integrate both the revealed and stated preference model in one structure that can be used in the TREMOVE framework. This comes down to preserving the (real-world) sensitivity of the revealed preference model and applying a factor to the coefficients of the stated preference model such that the ratio of the different coefficients does not change. One should however be careful by comparing coefficients, taking into account the nested structure of the models (see Figure 6).
A separate model for small cars only was designed using the large-car model as a base: the structure and the coefficients are identical. Whereas the large cars choice model has two size nests (medium and big) at the highest level of the model structure (see Figure 6), for the small cars model we only have one nest at that level.
For the large cars model, the coefficients of the inclusive value of the size nests were estimated (see Table 5). They are a measure for the difference in sensitivity between the different levels in the modelling structure. We assume the sensitivity for small cars to be similar to what has been estimated for medium and big cars, hence a value of 0,1 was chosen for the inclusive value coefficient of small cars.
Additionally, we assume a diesel dummy of -0,1 in order to get realistic diesel shares compared to 2002 observation figures.

A more elaborate description of the revealed preference model design and the integration with the stated preference model is provided in annex IV.

Table 5: coefficients of revealed preference and integrated private car technology choice model

Variable Description	Unit	*RP nested logit* Coefficient	*integrated model* Coefficient
Lifetime cost / quarterly GDP per inhabitant	LFC in €/vkm; GDP in 1e4 €	-0,4585391	-0,4585391
Available luggage space	%		0,1039
Emissions	%		-0,07853
Range	100 km		0,02906
Diesel	dummy	0,1938844	0,1938844
LPG	dummy		-0,06112
Fuel cell	dummy		-0,0652013
Battery	dummy		-0,1006130
Acceleration 0-100 km/h	s	-0,045565	-0,045565
quarterly GDP per inhabitant * Big	1e4 €	1,738	1,738
Big (+2l)	dummy	-2,510469	-2,510469
Inclusive value non-electric/fuel cell			0,62036
Inclusive value medium		0,1100573	0,17741
Inclusive value Big		0,156294	0,25194
Inclusive value hybrid/conv		0,2	0,2

2.3.2.6 Buses

Buses are not included in the initial vehicle stock module of TREMOVE (see Figure 3). As the focus of the SUSATRANS project is on passenger transport as far as alternative technologies are considered, we decided to extend the TREMOVE structure in order to fully account for bus stock turnover, including a technology choice model.

The technology model has to simulate market shares of different alternative technologies selected in task A (see part 3).

Compared to private car technology choice, not much literature has been devoted to purchase of alternative fuel technologies for heavy duty applications. Parker et al. (1997) [26] conducted a survey and found that price (ownership cost) seems to be the major (if not only) decision variable in the USA when it comes to purchase of trucks by transport companies. This is explained by the very competitive character of the trucking industry. The same reasoning seems to hold for bus operators, so we decide to include only price as technology variable in the choice model.

As we could not find any research on discrete choice modelling of technology choice upon bus purchase, and no data for estimation are available, we opted for a small multinomial logit choice model.

A first assumption is that alternative technologies for buses are not introduced for coaches in the modelling period. In TREMOVE we keep the share of coaches (approx. 20%) in overall bus sales constant to the observed 1995 level.

For the remaining buses (approx. 80%), the share of technology i is modelled by the formula:

$$Share_i = \frac{e^{-40 \cdot LFC_i}}{\sum_{j=tech} e^{-40 \cdot LFCj}}$$

with LFC_i the lifetime cost (€2000 per km) for technology i.
The LFC coefficient (40) has been assumed and found to be realistic by sensitivity analysis.

2.3.2.7 LDV, HDV and motorized two-wheelers

For LDV (freight) and motorised two-wheelers, we decided to stick to the existing approach in TREMOVE 1.3a, as no sustainable technologies have been studied in Task A (see paragraph 2.2) for these modi. The approach considered uses only lifetime cost as decision variable. We however reviewed the lifetime cost coefficient and recalibrated the technology dummies so to reproduce observed 1995 shares[7].
There are two multinomial logit models, one for LDV and one for motorized two-wheelers (except mopeds). The formula for the share of technology i is:

$$Share_i = \frac{e^{dum_i - \beta_{cat} \cdot LFC_i}}{\sum_{j \in cat} e^{dum_j - \beta_{cat} \cdot LFC_j}}$$

with

- cat: the technology class (HDV, LDV or motorcycles)
- LFC_i: the lifetime cost of technology i
- β_{cat}: the lfc coefficient for cat

The assumed values for β_{cat} are 25 for LDV, 10 for HDV and 5 for motorcycles. These values were found to be realistic by sensitivity analysis.
The higher β_{cat} value for LDV -which means a higher price sensitivity- can be motivated by the difference in choice modelled: for motorcycles these are different engine sizes and for HDV different gross weight classes rather than different fuels as is the case for LDV. A similar difference in sensitivity has been found to exist for private cars where both the choice between engine sizes and fuels is considered (see inclusive values for medium and big in Table 5).

2.3.2.8 Base Year data

To initialize the stock module of TREMOVE (see Figure 3), base year stock composition had to be collected.
The base year selected in the SUSATRANS project is 1995. Stock composition for this year has been taken from the TRENDS project [27].

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[7] Data limitations did not allow to use a more recent observation for model calibration.

2.3.3 Internal cost of transport activity

The internal cost of transport activity is one of the key drivers of the TREMOVE model.
For the TRE transport activity module (see Figure 3), the ex-post general cost of each demand category is calculated in the TREMOVE model based on the different cost components.
For the MOVE vehicle stock module, the ex-ante lifetime cost of each vehicle technology enters the choice model in order to calculate the shares of the different alternatives.
For an in depth discussion of the generalized price concept as well as the lifetime cost we refer to the model documentation [10].
The existing version of TREMOVE did not include a lifetime cost calculation for buses, considered that these vehicles are not included in the stock module. The extension of the stock modules discussed in paragraph 2.3.2 requires a lifetime cost calculation for buses. This calculation does not differ from the other technologies and is hence extended to include bus technologies.
The generalized price calculation for buses is rather rough in the existing version of TREMOVE. For the purpose of the SUSATRANS project we decided to refine the resource cost component, in order to more consistently assess policy measures. The new resource cost calculations are based on the different internal cost components (drivers' wage, vehicle costs, fuel costs) and accounts for the peak-loading principle that says that vehicle costs should be assigned to peak hours operations since the stock is dimensioned for peak demand. Furthermore subsidies have been made endogenous and are assumed to amount to the difference between resource costs and ticketing revenues. The ticketing revenues are fixed exogenously in the BAU scenario.
A final extension in the internal cost calculations is related to the introduction of an emissions tax and is discussed in paragraph 5.

2.4 Emission modelling (Task D)

In this section we describe the models used within SUSATRANS to determine the emissions from road transport, rail traffic and inland navigation.

2.4.1 TEMAT model for road transport

2.4.1.1 TEMAT 2000

In 2000 VITO developed TEMAT (Transport Emission Model to Analyse (non-) Technological measures) [28, 29]. TEMAT is a member of the COPERT emission modelling family [30]. The basic formula for transport emissions consists of three main components:

Emission/year = number of vehicles x emission factor x activity/vehicle/year

[amount] [g/km] [km/(vehicle*y)]

TEMAT contains both historical and future vehicle fleets. The vehicle turnover is determined on the basis of the historical vehicle stock, survival curves and yearly mileage by each type of vehicle, and future mobility demand.

The combination of detailed data on vehicle stock, yearly mileages, traffic situation and specific energy consumption and emission factors results in total energy consumption and emissions. The data can easily be processed, to fulfil specific requests.

Speed dependent emission functions are applied as reported in MEET and COPERT III [30, 31]. The final emission factors differ according to calendar year, fuel type, vehicle category, vehicle age, emission standard, road type, traffic type and cylinder capacity, size class or gross tonnage.

We distinguish five main vehicle categories: passenger cars (including mini buses), light duty freight vehicles, buses, heavy-duty freight vehicles and motorised two-wheelers. Besides the conventional fuel types gasoline, diesel and LPG (Liquefied Natural Gas), TEMAT 2000 integrated some alternative fuels i.e.: CNG (compressed natural gas), electric, hybrid, fuel cell methanol, fuel cell hydrogen and biodiesel.

TEMAT 2000 calculates the emissions of CO (carbon monoxide), CO_2 (carbon dioxide), NO_x (nitrogen oxide), VOC (Volatile Organic Compounds), PM (particulate matter), SO_2 (sulphur dioxide) and Pb (lead). Three road types are distinguished: urban, rural and highway. Furthermore, we distinguish normal and peak traffic. All these parameters can be extended depending on the needs.

TEMAT can be used at regional or national scale for annual emission estimations from transport. It is also a database in which input and output data can be shown detailed or summarized.

2.4.1.2 TEMAT 2004

Within SUSATRANS VITO extended, updated and validated the emission model for road transport. This resulted in TEMAT 2004 with a time horizon up to 2020.

Extension of the vehicle stock:

- small diesel cars (cc < 1,4 litre);
- redistribution of the heavy trucks over the different weight classes, therefore VITO used data on the number of axles determined by federal traffic counts and own traffic counting [32, 33];
- adjustments to the alternative motor fuels and technologies based on the findings in Task A (see Table 12 and Table 13).

New pollutants:

- greenhouse gasses: methane (CH_4) and dinitrogen oxide (N_2O) [30];
- PM for non-diesel vehicles [34, 35, 36] and Task A;
- individual NMVOC (non-methane VOC) species for gasoline, diesel and LPG [30].

Update vehicle stock:

- historical stock 2000 until 2003 [37];
- possibility of the introduction of alternative motor vehicles (see Table 12 and Table 13).

Update activity figures:

- 1990-2003 data on total mobility demand and distribution over different vehicle categories [38];
- yearly mileages tuned to latest available statistics [39].

Adjustment of emission functions/factors:

- NO_x and PM conventional fuels [40];
- emission factors for alternative motor vehicles, derived from Task A, see Table 29 for fleet emission factor per vehicle category, fuel and motor technology;
- emissions during the production of fuels derived from Task A.

For the validation of TEMAT 2004 we refer to annex V.

2.4.2 Rail traffic

VITO aimed to develop a model to estimate total energy consumption and emissions from rail traffic for 1990 until 2020. Initially we made a distinction between:

- type of service (passengers, freight);
- type of traction (diesel, electric);
- type of vehicle category (locomotive, railcar, high speed train);
- generation of propulsion engine (e.g. pre-UIC, UIC I, UIC II, EC stage IIIA, EC stage IIIB) [41, 42].

The National Railway Company of Belgium (NMBS/SNCB) supported VITO with statistical data on vehicle stock, activity figures and total energy consumption for passenger and freight transport separately, making a distinction between diesel and electrical traction [43]. However, the degree of detail was insufficient to make a distinction between different generations of technologies.

For direct emissions of diesel trains VITO decided to work with constant emission factors. We found a wide range in emissions per kilogram diesel. We took the numerical average of three sources, see Table 6. For sulphur we took into account the actual sulphur content of 1,7 g/kg diesel from 1990 until 2002 and 0,047 g/kg since 2003 [44, 45]. The basis for the calculation of indirect emissions – emissions during the production of diesel - is given in Table 7. Fuel production values for diesel used in trains are identical to those of road vehicles.

Table 6: emission factors for diesel power trains, g/kg fuel consumed [46, 47, 48]

Source	CO_2	NO_x	NMVOC	PM	CH_4	N_2O
MIRA-S2000	3210	50	14,0	3,5	~0,3	~0,4
IPCC	3155	54	5,0	2,9	0,18	
EcoTransIT	3170	55	4,9	1,5		
SUSATRANS	3178	53	8,0	2,6	~0,2	~0,4[8]

Table 7: evolution average emissions in g per MJ diesel [49, 50]

g/MJ	2000	2010	2020
CO	0,0049	0,0049	0,0049
NMVOC	0,088	0,088	0,088
NO_x	0,036	0,036	0,036
PM2,5	0,0010	0,0010	0,0010
SO_2	0,048	0,048	0,048
CO_2	10,4	12,0	12,0
CH_4	0,017	0,017	0,017

Electric trains do not generate emissions at the vehicle itself, so emission factors were set zero. The basis for the calculation of indirect emissions – emissions during the production of electricity - is given in Table 8. CO_2 figures from Electrabel 2001 were taken for 2000 and 2010. For 2020 we assumed the run-down in nuclear power plants. The European fuel mix to produce electricity is then used as a standard [49].

Table 8: evolution average emissions in g per MJ electricity produced [49, 50, 51]

$g/MJ_{el.}$	2000	2010	2020
CO	0,0083	0,0083	0,0083
NMVOC	0,0050	0,0050	0,0050
NO_x	0,12	0,12	0,12
PM2,5	0,010	0,008	0,006
SO_2	0,117	0,093	0,075
CO_2	80	80	128
CH_4	0,001	0,001	0,001

Within the emission calculations of rail traffic we took into account a further electrification until 2010, afterwards the share of diesel and electric trains stays the same as in 2010, see Table 9.

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[8] We did not take into account the high level reported for N_2O by IPCC (1,24 g/kg). This could be integrated in future studies.

Table 9: share of diesel in the total activity of rail traffic in Belgium [43]

Share of diesel %	1990	2000	2010	2020
Passenger	7,1	3,8	3,9	3,9
Freight	38,2	27,2	21,9	21,9

In annex VII more information is given on the vehicle stock, fuel and emission regulation, and infrastructure of rail traffic in Belgium. Annex VII also contains an overview of measures to reduce energy consumption and emissions from rail transport.

2.4.3 Inland navigation

Within SUSATRANS and a study for the Flemish organization for the promotion of inland shipping [52], VITO developed a technology model to calculate fuel consumption and emissions from inland vessels in Belgium. Transport between Belgian seaports is not included in the model.

The basis for the calculations are on the one hand the amount of tonne kilometres transported on Belgian inland waterways and on the other hand fuel consumption figures and emission factors per tonne kilometre. Historical figures for tonne kilometres are available at NIS (Belgian National Institute of Statistics) [53]. Future trends are estimated by VITO and CES.

Estimating fuel consumption and emission factors per tonne kilometre is much more complicated. VITO started from specific fuel consumptions and emissions in g/kWh as given by Hulskotte et al. (2003) for seven generations of technologies [54]. Hulskotte et al. gives no figures for the next generation of engines, i.e. CCR 2 or EC stage III certified propulsion engines, which will be operative in 2009 [42]. VITO deduced emission factors for this future engines from the figures for CCR 1 engines from Hulskotte et al. by multiplying them by the emission ratio CCR 2 to CCR 1. Fuel consumption for CCR 2 and EC stage III engines were taken equal to that of CCR 1 engines.

We processed the figures of the eight engine generations to come up with a specific fleet fuel consumption rate and fleet emission factors for the years 1990, 2000, 2010 and 2020. To do so we needed the segmentation over the eight generations of the propulsion engines used on the Belgian waterways. We could derive this segmentation from the fuel consumption inquiry VITO performed in 2003 [52].

We converted these fleet fuel consumption rates and emission factors to g/kg fuel and then used them as an input in the emission module from IVM (University of Amsterdam, 2000) which converts the rates to g/tonkm [55]. We made a distinction between motor ships and pushed convoys. Based on the share of push convoys given by NIS we came up with fleet consumption and emission rates for propulsion engines for loaded ships.

On these rates we added a correction factor for empty trades based on the figures of NIS about the share of empty ships in the total kilometres travelled on Belgian waterways and taking into account the lower consumption during empty trade. Fuel consumption during empty trade is about 72,5 % of consumption during loaded trade [52].

Finally, we made a correction for the energy used by auxiliaries: the bow screw propeller engine to manoeuvre a ship and the generators for electricity, … This was found to be 1,15 [52]. The emission model has been calibrated for the year 2002 with the findings of the fuel consumption inquiry.

Hulskotte et al. published no figures for N_2O, so we used figures from STOWA [56].

Table 10 gives an overview of the evolution of the fleet emission factors for inland navigation in Belgium expressed in gram per 1000 tonne-kilometre. The figures take into account the emissions due to propulsion engines and auxiliaries, also empty trade is incorporated.

Table 10: fleet emission factors for inland navigation in Belgium, sum of propulsion engines and auxiliaries, taking into account empty trade, in g/1000tonkm

Year	CO_2	NO_x	NMVOC	PM	CH_4	N_2O
1990	33 100	781	41,3	31,2	1,27	7,3
2000	29 700	573	28,8	20,9	1,14	6,5
2010	28 000	489	17,5	14,8	1,07	6,2
2020	27 700	361	12,1	8,6	1,06	6,1

The basis for the calculation of indirect emissions – emissions during the production of gas oil - is given in Table 7. Fuel production values for fuel used in inland vessels are identical to those of road vehicles and diesel trains (Table 6).

De Vlieger et al. (2004) provides more information on the energy consumption survey and the current and future legislation on fuel consumption and emission regulation of inland vessels [52]. This reference also discusses the feasibility of new technologies to further tighten up emission regulation for inland vessels.

2.5 ExternE methodology (Task D)

2.5.1 Introduction

The European series of projects commonly called "ExternE" are concerned with the health effects of complex mixtures of air pollution from electricity production and transport. These mixtures vary by location, technology, time and many other factors. It was and is impossible to evaluate the health effects of all these mixtures directly in human studies. Our approach in ExternE has been to construct a representation or a model of the health effects of these complex mixtures. This was done by selecting the key pollutants of the mixture which were, based on epidemiology and toxicology, believed to be adversely related to health. For some pathways, notably particles and acute mortality, or acute hospital admissions, the epidemiological data are very reliable. The strength of evidence has been summarised well as "strong evidence of a weak effect". For acute mortality and particles there are upwards of 50, possibly 100, well-conducted studies of different locations and/or years. These include two major multi-city studies, APHEA in Europe and NMMAPS in the USA, both designed with a view to meta-analysis. Astonishingly, both meta-analyses give very similar results: an increase of about 0,2 % - 0,6 % in daily mortality per 10 µg/m³ increase in PM10. There is also very strong evidence, from numerous studies, linking daily ozone with acute mortality and respiratory hospital admissions.

Based on current understanding (primary and secondary) particles and ozone are considered to be the main drivers of the pollution mixture. A set of exposure-response (E-R) functions which was as comprehensive as possible (containing over 30 health endpoints) for particles and for ozone was constructed. Effects of these two pollutants were considered to be additive. In recent ExternE work some CO and SO_2 functions are also included. ExternE was driven by the need to construct a useable model to assess externalities from energy production and transport. Like any model it is a simplification of reality.

2.5.2 Health effects of exposure to particulates

Although there has grown a consensus on the adverse health effects of PM, not all aspects are well understood. For several recent years, it was understood that estimated PM risks in the US studies were higher, per µg/m^3 PM10, in the US than in Europe. This was noted and discussed by the APHEA authors [57] but without explanation. Consequently, in ExternE in recent years, several E-R functions for particles and health based on US studies have been scaled down with the aim of improving transferability to Europe (see below). Within the range of uncertainty, PM risks are similar throughout the world.

The exposure-effect relationship that is by far the most important in the estimate of the total impact is the effect on chronic mortality. From the available studies, ExternE has used E-R functions based on Pope et al. (1995) [58] for this endpoint until the year 2000. However, different functions have been used at different times, as follows.

- ExternE (1995) (used for sensitivity analyses only) and 1997 Methodology (ExternE National Implementation Project) used an E-R function based on Pope et al.'s analysis in terms of PM2.5, because we considered this function more reliable than the alternative one in terms of sulphates (This was because sulphates are unlikely to be the main particulate driver of adverse health effects.)
- For the ExternE-core-Transport project (Int Panis & De Nocker [59] in Friedrich & Bickel 2001) [60] the mid-estimate scales down the PM2.5 function (converted to PM10) by a factor of three, to take account jointly of possibly higher exposure historically, and of what, at the time, seemed to be more extreme acute effects of particles on mortality in US studies compared with those in Europe (see above).
- For this study we use the most up-to-date approach which was developed during the NewExt (2003) and ExternE-POL (2004) projects and also serves as a basis in the CAFE discussions (2005) detailed below.

When calculating the external costs and using the functions on chronic mortality, functions on acute mortality (e.g. from APHEA) are not included, to avoid double counting.
For chronic mortality (the dominant end point in terms of costs) the E-R function has been revised on the basis of the cohort study of Pope et al (2002) [61], assuming a relative risk of 1,06 (for 10 $\mu g/m^3$) as the outcome of their meta-analysis based on the two values of 1,04 and 1,06 reported in their paper. In addition, there are very new insights into the relative toxicities of the different PM components.

For the ExternE reports of 1998 and 2000 the assumption was made that the toxicity of all sulphates is equal to that of PM2.5 and the toxicity of particulate nitrates equal to that of PM10. This distinction between sulphates and nitrates was based only on size, noting that nitrates need other particles to condense on, whereas sulphates self-nucleate and are therefore smaller on average. The ratio of E-R function slopes was taken as 0,6, because this is a typical value of the ratio of concentrations of PM2.5 and PM10. The composition and toxicity of primary PM emitted by different sources can be quite different; for example, automotive PM is almost entirely organic or carbonaceous whereas PM from coal combustion contains in addition a sizable portion of minerals. Since the available emissions data are simply stated in terms of PM mass, the best one can do is distinguish different typical PM compositions according to their source. ExternE treats power plant emissions as PM10 and vehicle emissions as PM2.5. Therefore ExternE now treats:

- nitrates as equivalent to 0,5 times the toxicity of PM10 (or 0,3 times the toxicity of PM2.5);
- sulphates as equivalent to PM10 (or 0,6 times PM2.5);
- primary particles from power stations as equivalent to PM10;
- primary particles from vehicles as equivalent to 1,5 times the toxicity of PM2.5.

Thus one can say for example that, per $\mu g/m^3$, primary particles from vehicles are 2,5 times as toxic as sulphates and 5 times as toxic as nitrates; and a mixture of 50 % primary particles from vehicles, 30 % sulphates and 20 % nitrates would have toxicity almost exactly the same as general urban PM2.5 mixture.
These relative risks are then converted to a YOLL-value (Years of Life Lost) using a complex life table approach. This gives estimated impacts in terms of years of life lost (YOLL), at various ages and at various calendar years in the future.

The calculation of external costs of energy is a very difficult and complex activity, involving a wide range of different types of expertise from atmospheric modelling to environmental policy analysis. The main elements of the methodology have been developed and applied in preceding phases of ExternE, but continual improvements are required. We have therefore chosen to embed this project into the most up-to-date framework currently used for CAFE rather than using the costs per tonne published earlier (e.g. Friedrich & Bickel, 2001 which is now outdated), since this would lead to a flawed analysis that is out of step with current best practice.

2.5.3 Global warming impacts

Tol et al. (2001) [62] proposed a range as a best estimate for CO_2 of 0,1-16,4 euro/tonne, which is often wrongly averaged to 2,4 euro/tonne. This estimate is one of several given in this book, each estimate referring to a specific set of assumptions about the PRTP (Pure Rate of Time Preference), discounting and equity. Depending on the question at hand other sets of assumptions are equally valid and generally result in higher estimates.

In a recent re-analysis (Tol, 2005) [63] the same author finds that the average estimate of 103 studies on the subject is \$93/tC (25\$/tCO_2). A value that is very close to the average abatement cost in the EU for which values of 19-20 euro are often cited and used. Consensus has existed since the early 1990'ies. To emphasise the wide uncertainty we have chosen to use the log-normal distribution of Tol (2001) with a geometric average of 66.1 euro/ton C, the 95% interval of which approximately spans most of the values cited above (Figure 7).

For the other GHG the 1% PRTP, World Average values were chosen (cfr. Friedrich & Bickel, 2001).

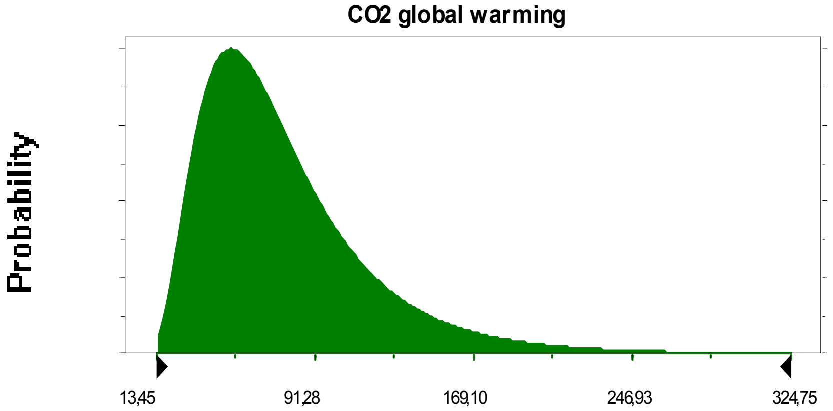

Figure 7: probability distribution used for sampling possible values for Global Warming impacts attributed to CO_2-emissions. 0% PRTP, EU-values worldwide (Tol, 2001)

2.5.4 Non-linear impacts of nitrates & sulphates with time

Many software packages (including EcoSense-versions from the ExternE projects), used to estimate annual average concentration increments, still use the outdated 1990 (Point Source version) or 1994 (Transport version) background emissions. However total emissions of secondary PM precursors have decreased and will continue to decrease over time. At the European level the decrease between 1990 and 2020 is projected to be 80 % for SO_2 and 60 % for NO_x (Figure 8); for individual EMEP grid cells (e.g. in Belgium) the changes can be even larger.

The resulting change of the atmospheric chemistry leads to higher impacts per tonne emitted, as illustrated by Figure 9 (calculated with the EcoSense Transport version). The original ExternE results (labelled '1990' and '1994 orig') are quite similar, but the costs per tonne are expected to rise significantly in the future. It is important to take this into account when analyzing policy decisions that take their full effect in 2010 or later. Using external cost data obtained with software using 1990 or 1994 background emissions could yield spurious results because the cost per one tonne of NO_X emitted will be more than twice as high in 2020 than it was in 1990. The emission of one tonne of SO_2 will also lead to sulphate impacts that are nearly twice as high in 2020 as compared to 1990. This effect can easily be understood from the EcoSense reaction scheme. Because the emissions of NH_3 are expected to stay at a similar level where NO_X and SO_2 decrease significantly, more NH_3 is left to react with the marginal emission increase. The ExternE-POL report (2005) therefore concluded that the continuous update of background emission files and the use of the correct files for the policy questions under study should therefore be a constant point of attention. The use of correct cost/tonne for a given year of reference is especially relevant for SUSATRANS.

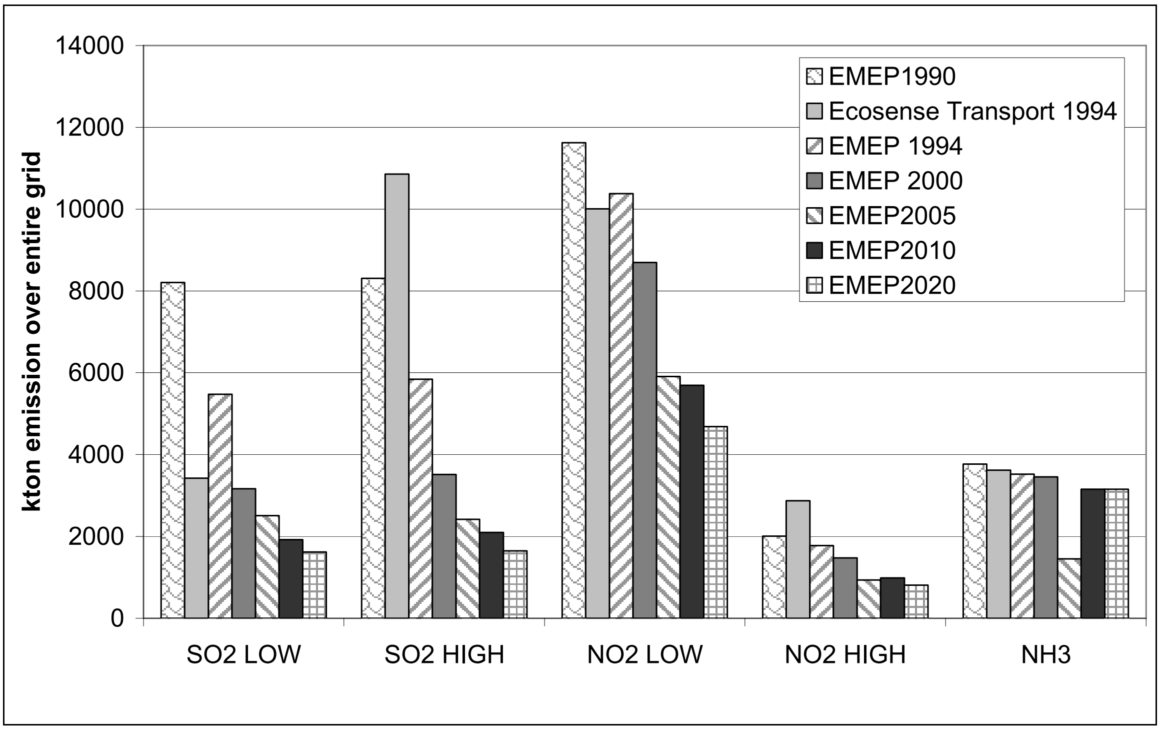

Figure 8: comparison of total emissions over the EMEP grid for different years.

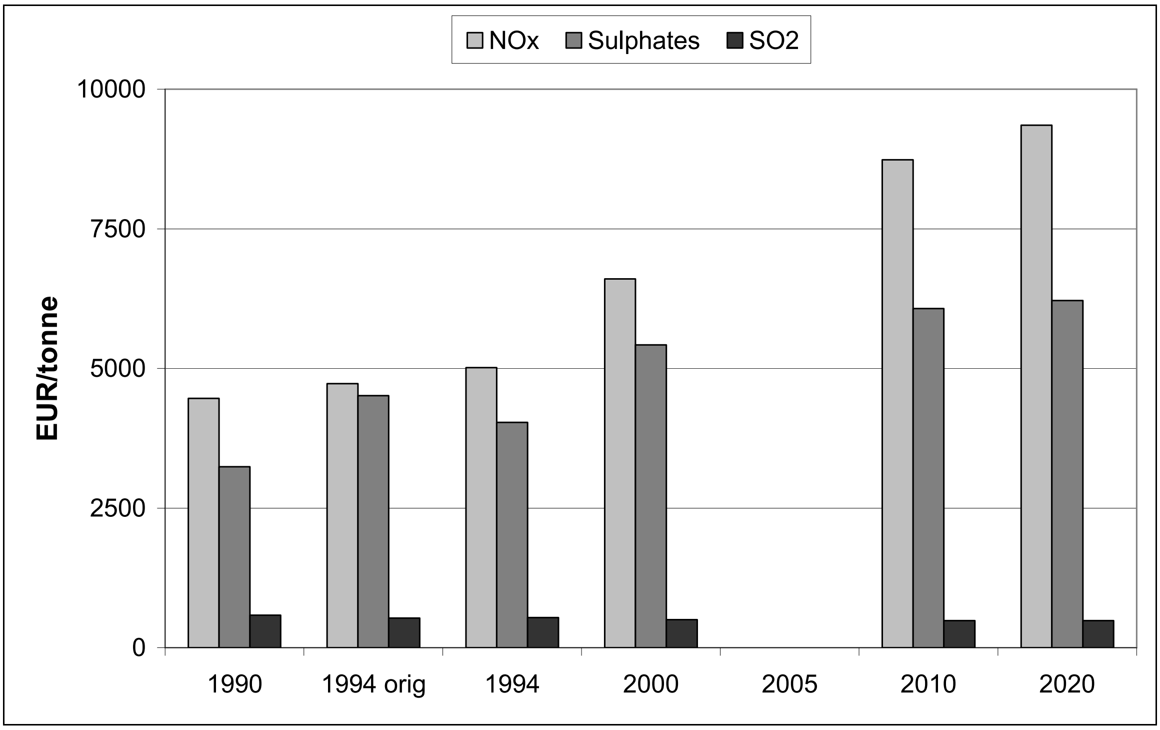

Figure 9: damage cost per tonne emitted under different background conditions (years).

2.5.5 Unit external damage costs for emissions

In Table 9 we provide a concise summary of the values derived by VITO using the arguments lined out above. They were subsequently used for calculations of total external costs with VITO's ExTC model. These values were converted for use in TREMOVE (see Chapter 5, Table 22).

Table 11: external damage cost per ton of pollutants emitted in different years

pollutant	*Location of source*	*1994*	*2000*	*2010*	*2020*
CO	Brussels (centre)	3,15	3,15	3,15	3,15
CO	Small city	1.06	1.06	1.06	1.06
CO	Rural village	0,83	0,83	0,83	0,83
NO_X	Brussels (centre)	5000	6600	8700	9400
NO_X	Small city	5000	6600	8700	9400
NO_X	Rural village	5000	6600	8700	9400
PM	Brussels (centre)	911572	911572	911572	911572
PM	Small city	308580	308580	308580	308580
PM	Rural village	102860	102860	102860	102860
N_2O[9]	Brussels (centre)	240-2836	240-2836	240-2836	240-2836
N_2O	Small city	240-2836	240-2836	240-2836	240-2836
N_2O	Rural village	240-2836	240-2836	240-2836	240-2836
NMVOC	Brussels (centre)	1100	1100	1100	1100
NMVOC	Small city	1100	1100	1100	1100
NMVOC	Rural village	1100	1100	1100	1100
CH_4[10]	Brussels (centre)	17-148	17-148	17-148	17-148
CH_4	Small city	17-148	17-148	17-148	17-148
CH_4	Rural village	17-148	17-148	17-148	17-148
SO_2	Brussels (centre)	10975	12349	13042	13135
SO_2	Small city	10975	12349	13042	13135
SO_2	Rural village	5623	6996	7689	7783
CO_2[11]	Brussels (centre)	5.2-62	5.2-62	5.2-62	5.2-62
CO_2	Small city	5.2-62	5.2-62	5.2-62	5.2-62
CO_2	Rural village	5.2-62	5.2-62	5.2-62	5.2-62

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[9] 99% confidence interval of the log-normal distribution, 1% PRTP, WA (geometric average: 49.5)

[10] 99% confidence interval of the log-normal distribution, 1% PRTP, WA (geometric average: 825.4)

[11] 99% confidence interval of the log-normal distribution, 0% PRTP, EU-values

3 RESULTS SUSTAINABILITY ASSESSMENT (Task A)

In this chapter we list the technologies involved on the one hand in the extended sustainability assessment performed by means of a multiple criteria analysis and on the other in the assessment executed with the TREMOVE model. The major results of the multiple criteria analysis are discussed. The sustainability ranking of the technologies is given for the years 2000, 2010 and 2020. Furthermore, we briefly deal with the sensitivity of the rankings.

3.1 Technologies involved

Table 12 shows the technologies that were taken into account in the detailed sustainability assessment for light duty vehicles (passenger car, mini busses and delivery vans) in Task A and the sustainability assessment performed with the TREMOVE model (Task B). Table 13 idem for heavy duty vehicles (urban busses and big trucks).

Biodiesel and diesel hybrid cars were included in the assessment after consultation of the user's committee on the first screening. Biodiesel (non-blended) was included because of the recent adoption of the European Directive 2003/30/EG. Hybrid vehicles running on diesel were included because of the promising possibilities of the fuel and on request of the user's committee.
By hybrid vehicles in Table 12 we mean mixed hybrid. A mixed hybrid system combines the advantages of a parallel and a series hybrid system. The combustion engine is mechanically coupled to the wheels, but at the same time through the combination with an electric motor/generator it can feed electricity to the batteries. A well known example is the Toyota Prius.

More detailed description of the properties of the fuels and the examined technologies, as well as the assumptions made upon the vehicles, can be found in annex I and annex II. The main references used to obtain the figures and characteristics of the technologies in these annexes are [49, 50, 64, 65, 66, 67, 68].

To give an idea of the complexity of the exercise, Table 14 shows the amount of files used during the evaluation.

Table 12: selected technologies for light duty vehicles

FUEL	PROPULSION SYSTEM
Conventional technology options	
Gasoline	Indirect injection
Diesel	Direct injection
LPG	Indirect injection
Alternative technology options	
CNG	Hybrid
CNG	Spark ignition engine
Gasoline	Direct fuel injection
Gasoline	Hybrid with indirect fuel injection
5% Biodiesel	Diesel engine
Electricity (average Belgian mix)	Battery and electric motor
Hydrogen from NG*	Fuel Cell
Hydrogen from NG	Hybrid with spark ignition engine
Hydrogen from NG	Spark ignition engine
Hydrogen from Biomass	Fuel Cell
Biodiesel	Diesel engine
Diesel	Hybrid

* NG = Natural gas

Table 13: selected technologies for heavy duty vehicles

FUEL	PROPULSION SYSTEM
Conventional technology	
Diesel	Direct injection
Alternative technology options (urban bus)	
CNG	Spark ignition engine
Electricity (average Belgian mix)	Battery and electromotor
Hydrogen from NG*	Fuel Cell
Biodiesel	Diesel engine
Diesel	Hybrid
5% Biodiesel	Diesel engine
Alternative technology options (heavy duty – freight transport)	
5% Biodiesel	Diesel engine
Synthetic diesel from Biomass	Diesel engine
Biodiesel	Diesel engine

* NG = Natural gas

Table 14: number of files used in the detailed sustainability assessment

	extension	file-type	used for	number	
input	arg	ARGUS data file	data of a multiple criteria (sub)problem	1495	**4.034**
	agd	ARGUS subcriteria import file	ARGUS results of subproblem to be imported as criteria	604	
	asf	ARGUS GDS import file	ARGUS results of one decision-maker to be imported in ARGUS GDS	893	
	acf	ARGUS preference structure	Preference structure of a criteria	1042	
GDS output	txt	text file	data files for GDS (year - transport-type level)	36	**108**
	txt	text file	results GDS heuristic method	72	
Clustering	txt	text file	data clusters (input)	56	**233**
	txt	text file	data to obtain cluster representatives (input)	56	
	txt	text file	cluster representatives (output)	60	
	jpg	screen capture	correlation tables	57	
	jpg	screen capture	overview	4	
					4.375

3.2 Ranking of technologies through multiple criteria analysis

For the ranking of technologies through a multiple criteria analysis (MCA) 36 decision makers have been involved. The evaluation criteria and approach used for this analysis are described in paragraph 2.2. In the following major results of the MCA are summarized, more details can be found in annex II.

An overview of the results of the extensive multiple criteria analysis are presented in Table 15. Ranking of technologies are given separately for light duty vehicles (passenger cars, mini busses and delivery vans), heavy duty vehicles freight (trucks) and busses. The rankings are listed for the years 2000, 2010 and 2020. Occurrence of different fuel and motor technologies in the same rank, means that the global sustainability as defined within Task A of these options are comparable to each other.

Table 15: overview of the sustainability ranking of light duty and heavy duty technologies

Light duty vehicles

	2000	**2010**	**2020**
Rank 1	LD LPG	LD electric	LD 5%biodiesel
Rank 2	LD diesel LD CNG LD hybrid gasoline	LD biodiesel	LD electric
Rank 3	LD 5%biodiesel LD biodiesel LD electric	LD 5%biodiesel	LD diesel LD biodiesel LD IDI gasoline LD DI gasoline LD LPG LD CNG LD hybrid diesel LD hybrid CNG LD fuel cell H2 from NG
Rank 4	LD IDI gasoline	LD diesel LD hybrid CNG	LD hybrid gasoline
Rank 5	LD DI gasoline	LD IDI gasoline LD DI gasoline	LD fuel cell H2 from biomass

Rank 6		LD hybrid diesel	LD hybrid H2 (ICE)
Rank 7		LD LPG LD fuel cell H2 from NG	LD H2 (ICE)
Rank 8		LD CNG LD hybrid gasoline	
Rank 9		LD H2 (ICE) LD hybrid H2 (ICE) LD fuel cell H2 from biomass	

ICE: Internal Combustion Engine

Freight transport

	2000	**2010**	**2020**
Rank 1	HD freight biodiesel	HD freight synth diesel	HD freight synth diesel
Rank 2	HD freight diesel HD freight 5%biodiesel	HD freight diesel HD freight 5%biodiesel HD freight biodiesel	HD freight diesel HD freight 5%biodiesel HD freight biodiesel

Busses

	2000	**2010**	**2020**
Rank 1	HD bus diesel HD bus 5%biodiesel	HD bus diesel HD bus 5%biodiesel	HD bus electric
Rank 2	HD bus biodiesel HD bus CNG HD bus electric	HD bus hybrid diesel	HD bus hybrid diesel HD bus CNG HD bus fuel cell H2
Rank 3		HD bus biodiesel	HD bus 5%biodiesel
Rank 4		HD bus CNG	HD bus diesel
Rank 5		HD bus fuel cell H2 HD bus electric	HD bus biodiesel

Table 15 shows a schematic overview of the sustainability of technologies for road transport in the period 2000 to 2020. In the following we briefly discuss this table, more detailed information upon the multiple criteria analysis could be found in annex II.

The ranking of gasoline passenger cars in the sustainability ranking for the years 2000 and 2010 is poor. Reasons behind this are mainly the lower energy efficiency and the higher greenhouse gas emission of gasoline cars and the higher emissions during production of the fuel.

At present (2000) LPG and CNG passenger cars, directly followed by diesel and hybrid gasoline vehicles, score the best on the sustainability barometer. LPG and CNG vehicles will in the near future (2010) be overtaken by vehicles running on biodiesel. Passenger vehicle technologies running on diesel, still score quite high in 2010 because of the introduction of the particle filter and the DeNOx converter. However, if these systems are not standard technology on 2010 diesel (biodiesel) vehicles, their sustainability ranking would be considerably less.

In 2010 hybrid passenger cars and other alternatives are still lower on the sustainability barometer than conventional vehicles, mainly because of their higher cost.

Furthermore, there is a lack of clarity on the sustainability ranking of electric passenger cars in 2010. No explanation can be given why the ranks vary so much. It could mean that there are only very small differences between the rankings of the technologies and that the electric vehicles could be equivalent to other conventional technologies. Hydrogen vehicles, however, are not yet very sustainable compared to other technologies in 2010.

In the midterm future (2020) electric passenger cars (charged from the net) and hybrid passenger cars (on CNG and diesel) will climb on the sustainability ranking, as will fuel cell vehicles driven on hydrogen made from natural gas. Other hydrogen technologies (based on combustion engine technology) are less sustainable. This is because the production of hydrogen requires a lot of energy (and generates CO_2 emissions, especially when produced from fossil fuels like natural gas), while the hydrogen combustion engine is not significantly more efficient than conventional combustion engines (this in contrast to the fuel cell).

For passenger cars it can be concluded that in 2020 all technologies except hydrogen internal combustion engine technologies are well matched, due to:
- the technological evolution that vehicles on alternative fuels will have undergone;
- the reduction in costs for alternative vehicles and fuels that will have taken place.

An important fact within road freight transport is that synthetic diesel made from biomass would already rank above biodiesel and diesel on the short term (2010). This is remarkable since the production capacity at that time is still very limited. It shows the potential of the fuel.

Looking at the results for buses, a striking result in the ranking of the present technologies (2000) is that electric buses score lower than conventional buses, even lower than buses that run on CNG. This is mainly due to the lower economic performance of electric buses at present. Their lifetime is currently lower compared to conventional diesel buses and their purchase cost is considerably higher than for diesel buses.

In the near future (2010) there is no major shift in the ranking. Diesel buses (also considered here are diesel buses with addition of 5% biodiesel) with conventional engines and in hybrid configuration still dominate. The lifetime of electric buses has increased and purchase cost dropped. Still it is not yet in a position to effectively compete with conventional technology. An exception is the hybrid diesel bus. It can be compared with a conventional diesel bus. The hybrid diesel bus has a slightly worse performance on the social aspects (reliability and acceptance), but is more environmental friendly.

Only in 2020 alternatives for buses will become more sustainable and conventional technologies will drop in the ranking. Especially the improvement in economic performance is remarkable. This can be explained by the fact that the lifespan of electric, hybrid and fuel cell buses increases steadily. The increase in lifetime of the buses goes together with a decrease in purchase cost. The combination of these two aspects makes that the economic performance of these technologies improves a lot.

Within the SUSATRANS project different technologies were evaluated upon their power train and the according fuel for a time horizon up to 2020, no brands were evaluated. Beside current technologies also technologies for the year 2010 and 2020 are handled. For the ranking of vehicles in a less aggregated way (individual brands and vehicle type) we refer to the approach used in the Ecoscore project. In the Ecoscore project VITO and VUB worked out an environmental rating system (only) for current specific (~ brands) vehicles. Neither economic nor social criteria are taken into account in the Ecoscore project [69].

3.3 Sensitivity and clustering

3.3.1 Sensitivity analysis

We performed a sensitivity analysis on the weights attributed to the four sustainability aspects. Besides the weights as mentioned in Table 1, three other weight scenarios have been defined. The first scenario looks at the ranking of the technologies when all four aspects are given the same weight. Scenario 2 does the same, but there the technological aspects are not looked upon. This scenario was created because normally sustainable development is considered to be constituted of a social, economic and an environmental pillar. The technological pillar was added because it was VITO's definition of sustainable technology. Scenario 3 has the same rational as scenario 2, but there the aspects are given the weight, the stakeholders attributed to them. Table 16 summarizes the scenarios and the attributed weights. Comparison of the rankings in the four scenarios learns that no matter which scenario is looked at, in 2000 and 2010 conventional technologies driven by LPG and diesel (with addition of 5% bio diesel) are the most sustainable technologies compared to others. On the short term biodiesel is a good alternative as well in combination with a traditional

engine as used in a hybrid car. It is only in 2020 that hydrogen and electrical vehicles will become more sustainable in relation to others. Detailed results can be found in annex II.
Looking to the individual criteria of the four aspects, we determined that decision makers pay a lot of interest to fuel consumption, greenhouse gas emissions and PM emissions.

Table 16: description of the scenarios and assigned weight for each aspect

Scenario	Description
Base	Each aspect of sustainability is given a weight according to the 36 stakeholders Technology=9 ; Society=10 ; Economy=9 ; Environment=12
1	Each aspect of sustainability is given an equal weight Technology=1; Society=1; Economy=1; Environment=1
2	Only the three aspects of sustainability are looked at and given an equal weight Society=1; Economy=1; Environment=1
3	Only the three aspects of sustainability are looked at and given a weight according to the 36 stakeholders (rescaled) Society=6 ; Economy=6 ; Environment=8

In the current study a sensitivity analysis by varying the values of the different criteria was not executed. Although the basic information is available to do so. However, such an exercise falls beyond the scope of the SUSATRANS project.

3.3.2 Clustering of the decision makers

The background of the decision makers was not the same: some decision makers were last-year students, others were academic personnel (professors, assistants,…), others were researchers of VITO, etc. There were also some other differences amongst the decision makers: age, experiences,…

The question can be asked if the background of the decision makers had an influence on the way they looked at the decision problem. To get an idea of this, the results of the decision makers on the group decision problem from 2010 for personal cars was taken and four cluster analysis were applied. The aim of the clustering was to visualize how the decision makers would find each other to form groups around certain "compromise solutions".

We could conclude that the groups of decision makers, which were formed during the clustering, did not correspond with the different backgrounds. There was no grouping of students, or of researchers,…. nor clusters with "younger" and "older" decision makers were formed. More detailed on the clustering can be found in annex II.

4 BUSINESS-AS-USUAL SCENARIO (Tasks A-E)

Two business-as-usual (BAU) scenarios were designed one by CES for the modelling period 1995-2020 and another more conservative by VITO for the period 1990-2020. A BAU scenario simulates what happens in a situation where no new policy measures are implemented apart from those already decided.

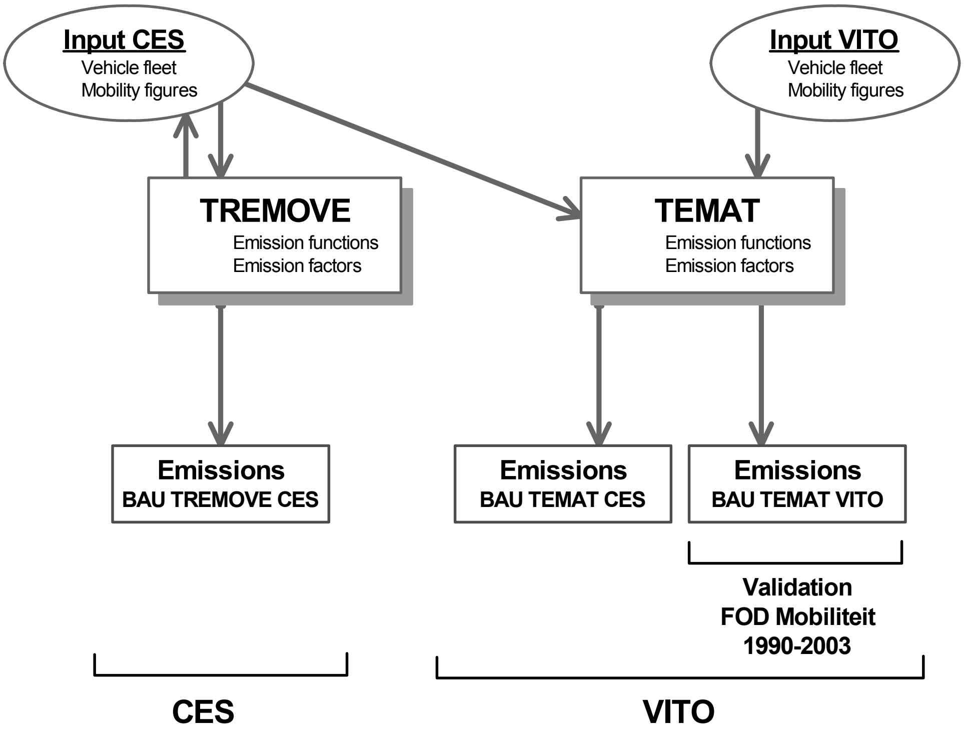

Figure 10: overview three sets of emissions determined within SUSATRANS

Within SUSATRANS we determined three sets of emissions for the business-as-usual scenario, see Figure 10:

- The TREMOVE business-as-usual scenario assessed by CES (BAU TREMOVE CES). This BAU-scenario leans on a European used model (TREMOVE) for the evaluation of policy scenarios and on basic information coming to a great extent from European institutes (see paragraph 2.3 and 4.1).

- The TEMAT business-as-usual scenario with input from TREMOVE CES (BAU TEMAT CES). This scenario applies transport emission models developed by VITO. In these models the emission module was used without adaptation to the TREMOVE emission module. However, data related to vehicle stock and traffic correspond to figures in BAU TREMOVE CES.

- The TEMAT business-as–usual scenario assessed by VITO (BAU TEMAT VITO. This BAU-scenario leans on transport emission models developed by

VITO. Basic information coming to a great extent from National and regional organizations (see paragraph 2.4 and 4.3).

4.1 TREMOVE business-as-usual CES (Task A, B)

A business-as-usual (BAU) scenario is constructed for the period 1995-2020. This scenario simulates what happens in a situation where no new policy measures are implemented apart from those already decided. The aim of the BAU scenario is to function as a reference for the policy scenarios (see chapter 5), to allow for a consistent assessment of the implementation of different policy measures aiming at a shift towards more sustainable technologies and modes.

One should however be careful not to consider the BAU scenario as a projection or forecast, TREMOVE not being a forecast model. The TREMOVE model is a simulation tool providing a consistent framework for the assessment of what would happen if the exogenous variables follow a given evolution. This allows for the assessment of different policy measures on a common base.

This paragraph discusses the specification of the BAU scenario. The first part focuses on the TRE module (see Figure 3), the second part deals with the MOVE stock turnover.

4.1.1 Transport activity: TRE-part

The TRE-part of the model is calibrated on the BAU scenario evolution of the transport activity demand. This evolution is mainly based on a draft version of the TREMOVE 2 baseline, which is in turn based on an updated version of the SCENES model [70] and the assumption of a constant growth rate. A short overview of the links between the different EU projects is provided in annex VIII.

In SUSTARANS, the evolution in the 1995-2001 period (up to 2002 for railways) has been brought in line with statistical observations as published in the DGTREN Pocketbook [71]. For the evolution beyond the statistical period the TREMOVE 2 constant growth rate has been applied. We verified this constant growth rate assumption and decided not to reject it[12].

Some smaller corrections to the TREMOVE 2 activity figures had to be made in order to fit the TREMOVE 1.3 classification. This included a split to alone/pool-taxi and the attribution of the full light duty vehicles activity to freight transport. An overview of the growth rates of (aggregate) demand classes can be found in paragraph 4.1.3.

In the existing TREMOVE model the congestion function had an exponential form (linking flow to travel time). This functional form was originally proposed by O'Mahony and Kirwan (2001) [72]. However past experience revealed that there are some

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[12] The evolution in TREMOVE 2 is based on the SCENES model results for 2020 which take into account the extension of the network capacity (TEN-networks). The question (not answered by SCENES) is if the growth will occur at a constant growth rate over the period 1995-2020. The assumption made here is that the pace of the infrastructure extension is such that the generalised price of transport (taking into account congestion) is increasing at a constant rate over time (which seems to be a reasonable assumption). Together with the constant growth of income and constant price and income elasticities, this results in a constant transport activity growth.

difficulties in using this function for simulation when calibrated on a limited dataset. Therefore a new functional form for the congestion function was selected:

$$V_{c,p,r,t} = A_{c,r,t} + B_{c,r,t}.F_{p,r,t}$$

where

- $V_{c,p,r,t}$ is the speed in year t in period p in region r for vehicle class c
- $F_{p,r,t}$ is the flow (in passenger car units per hour) in period p in region r
- $A_{c,r,t}$ and $B_{c,r,t}$ are coefficients
- c is the vehicle class: truck/bus or private car/motorcycle
- r is the region: Brussels, other urban, motorway or other road
- p is the period: peak or off-peak

The coefficients A and B of the congestion function are calibrated using TREMOVE 2 data (from the SCENES model). Speed differences between peak and off-peak are rather small (see Figure 26) as they concern speed averaged over the whole network, only a small part of it being congested during peak hours. These small differences have been found to be in line with existing observations (UK and Italy, see TREMOVE 2 documentation for more details).

Average speed of non-road modes has been taken from TREMOVE 2. Public transport walking and waiting times as well as speed for non-motorized transport have been based on TREMOVE 1.3 data. Value-of-time figures have been taken from TREMOVE 2.

Resource costs for non-road modes are not modelled in the TRE-part and are exogenous to the model. The values for these variables have been based on TREMOVE 2.

4.1.2 Vehicle stock: MOVE part

The input of the stock turnover module consists of a broad range of vehicle technology and fuel related properties. All of these variables need a BAU scenario evolution.

The technology choice models (see 2.3.2) are driven by cost data, functional car properties (e.g. luggage space), expected lifetime and mileage and GDP per inhabitant. Several sources have been used for the design of the BAU scenario evolution for all of these variables; we limit ourselves here to an overview of the most important ones.

Conventional fuel properties have been mainly based on IEA [73] for the base year fuel prices and taxes. The evolution of the ex-tax price was based on the PRIMES-transport model [74] (we refer to the PRIMES documentation for full details on the assumptions behind this evolution), the evolution of tax levels only accounts for the Cliquet system implemented by the Belgian federal government. Prices of alternative fuels have been taken from the detailed report of Task A (see annex II), Febiac [75] and Vrije Universiteit Brussel [50]. Taxes on alternative fuels have been assumed identical to gasoline[13]. Full details of the fuel BAU scenario can be found in annex IX. The BAU scenario for private cars and bus technologies has been based on a broad range of sources, including TREMOVE 2, the report of Task A and Vrije Universiteit Brussel. Expected lifetime and mileage per car data have been taken from the TRENDS project. Full details on all these assumptions can be found in annex IX.

We feel we should pay some attention here to the issue of the introduction date of the alternative technologies. The year that new technologies will leave the prototype stage and enter the market is very uncertain. After a first market entry it may again take several years before a technology becomes fully available with all manufacturers and car types. Many factors may speed up or down this process; several of them are beyond the scope of the TREMOVE model. This process can be described by the theoretical framework of experience curves as described by IEA [76]. We should however stress that such a process is not included in the TREMOVE model. To summarize: in TREMOVE technologies are fully available or not available at all at a given point in time. This seems not too bad an assumption for a long term model, the only disadvantage of this limitation is that it is not possible to simulate a shift of the introduction date depending on e.g. the number of units sold in the year before or efforts in research and development funded by the government.

That said, we need to fix an introduction date in TREMOVE for every alternative technology, and this date has to be the same in both the BAU-scenario and the policy measure simulation. We have chosen to be rather optimistic on the full market availability of the different technologies (in line with the report of Task A[14]; see Table 17 and Table 18). This may be too optimistic, but here we should draw again the attention of the reader to the purpose of the project: study policy measures aiming at a technology and/or modal shift to enhance sustainability. In case pessimistic introduction dates were selected (e.g. 2019), not much shift between technologies could be simulated as the modelling period ends in 2020 and no stock turnover would happen. The option exists to shift the introduction date exogenously between BAU-scenario and policy simulations. However, this would not leave much space for conclusions regarding the measures taken, these measures not being clear at all (unless you assume the Belgian authorities would start producing alternative cars themselves).

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[13] There are currently no or only small excise taxes on LPG, CNG and electricity. As we assume hydrogen to be based on natural gas, we assumed they are freed from excises as well. However, this would imply an indirect subsidy for CNG, electric or H_2 powered cars when they are introduced. For that reason, we assume an excise tax per unit of energy that is identical to gasoline.

[14] The report of Task A does not mention explicitly any introduction dates of the different technologies. The definition of the technological characteristics does however provide an indication of the availability of the technologies at a given point in time. Although it should be mentioned that VITO did not make any judgement on the full market availability of technologies in Task A.

Table 17: introduction year of private car technologies

Technology	*Size class*	*TREMOVE*
Diesel conventional	small	2002
Diesel conventional	medium, big	1995
Gasoline conventional	all	1995
LPG (retrofit)	all	1995
CNG (retrofit)	all	2008
Hydrogen ICE	all	2013
Diesel hybrid	all	2011
Gasoline hybrid	all	2006
CNG hybrid (retrofit)	all	2013
Hydrogen ICE hybrid	all	2013
Battery	small, medium	2008
Hydrogen fuel cell	all	2013

Table 18: introduction year of bus technologies

Technology	*TREMOVE*
Diesel	1995
Diesel hybrid	2013
CNG	2003
Hydrogen fuel cell	2013
Battery	2008

For the remaining road technologies (freight and motorcycles) the BAU scenario is based on TREMOVE Vlaanderen [77] and Vrije Universiteit Brussel (for repair and maintenance cost level).

Non-road modes do not include a stock turnover model; hence very limited data are necessary. For freight (rail and waterways) an assumption on the cost per tkm is taken from TREMOVE 2. For passenger public transport (train and metro) assumptions on the marginal operating cost is based on TREMOVE Vlaanderen, the revenue level (per pkm) is calculated based on annual reports from the operators (De Lijn [78], TEC [79], MIVB [80] and NMBS [81]) and the (negative) tax is calculated from both. The prices for public transport are assumed to stay constant in the BAU scenario. Occupancy rates for non-road modes are based on Eurostat figures [82].

4.1.3 BAU evolution

In this paragraph we first provide a summary overview of the BAU evolution: transport activity, vehicle stock composition and emissions.

In a next step we propose an indicator of the sustainability potential of different technologies and modes and discuss which technological and modal shifts are sustainable. To avoid any confusion on the topic "sustainability", we should stress here that the implementation of sustainability of technologies and modes in the framework of the TREMOVE model is different from the approach in Task A of the project (see chapter 3), which may result in different insights.

4.1.3.1 Transport activity

The evolution of transport activity in the BAU scenario is exogenous to the model and is based on draft TREMOVE 2 results (see 4.1.1). The growth figures are represented in Table 19 and Table 20.

Table 19: BAU scenario annual growth rate for passenger transport activity (pkm)

	95-00	*00-05*	*05-10*	*10-15*	*15-20*
non-motorized (urban only)	-0.21%	-0.21%	-0.21%	-0.20%	-0.20%
motorcycle	1.44%	1.58%	1.19%	1.27%	1.37%
private car	1.74%	1.22%	1.19%	1.27%	1.37%
buses	-0.16%	0.25%	0.11%	0.12%	0.13%
urban rail	1.69%	0.40%	0.34%	0.36%	0.37%
train	2.73%	2.11%	1.42%	1.58%	1.77%
total	1.51%	1.12%	1.04%	1.13%	1.23%

Table 20: BAU scenario annual growth rate for freight transport activity (in tkm)

	95-00	*00-05*	*05-10*	*10-15*	*15-20*
road	2,10%	2,96%	2,68%	2,69%	2,71%
rail	0,99%	0,80%	3,04%	3,05%	3,06%
IWW	4,69%	3,00%	2,73%	2,73%	2,73%
total	2,25%	2,69%	2,73%	2,74%	2,76%

4.1.3.2 Vehicle stock

The stock composition is provided in Figure 11 for private cars. One may consider the simulated penetration of new technologies as rather optimistic. We should however not forget the introduction assumptions made in the BAU scenario (see 4.1.2), in order to allow for a consistent policy measure simulation.

For buses, the share of alternative technologies is limited due to the modelling specification (see 2.3.2) including an assumption on a rather high price sensitivity in this sector.

For more figures on BAU scenario vehicle stock composition we refer to annex IX.

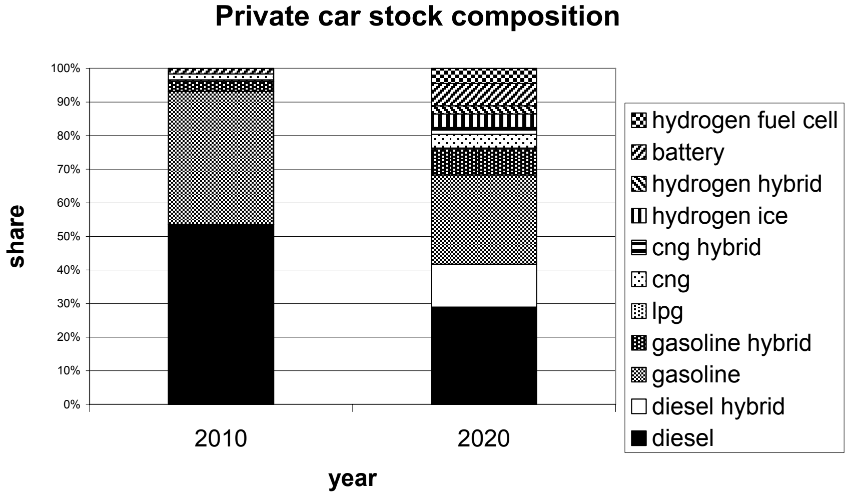

Figure 11: private car stock composition in BAU scenario

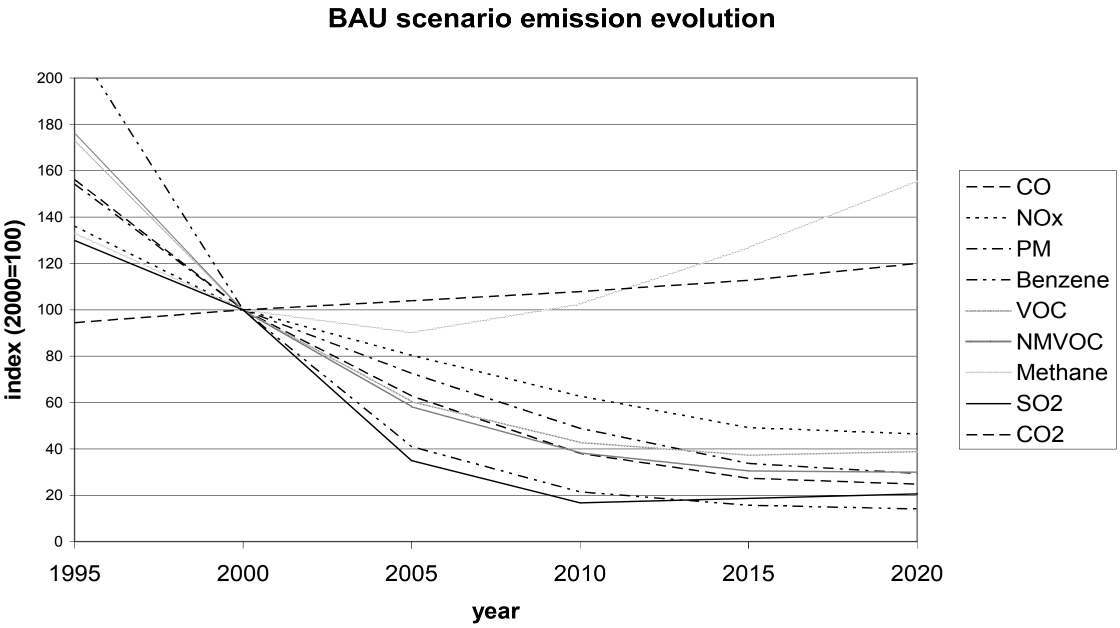

Figure 12: BAU scenario evolution of emissions

4.1.3.3 Emissions

The results of the emission module (see 5.1.1) for the BAU scenario are presented in Figure 12. We see a decline in most regulated emissions, only for CO_2 and for CH_4 is there an increase.

4.1.3.4 Sustainability of technologies in TREMOVE

The main driver of the technologies' shares in the stock composition is the composition of car sales. The shares of technologies in new car sales are determined by the choice models as explained in §2.3.2: the different technology properties enter the utility formula (see §2.3.2.2).

In the BAU scenario, the lifetime cost variable of the different technologies does not reflect environmental costs as they are external to the consumer and not fully reflected in the existing taxes. The choice of the consumer is hence not expected to reflect fully the environmental concerns.

Table 21: BAU 2020 comparison of technologies (monetised in € per vkm)

Technology	*BAU-scenario choice determinant*	*sustainability indicator*
Cars, dsl., small	0,40	0,42
Cars, gsl., small	0,00	0,00
Cars, cng, small	0,27	0,26
Cars, h2 ice, small	0,18	0,16
Cars, dsl. hybrid, small	0,44	0,46
Cars, gsl. hybrid, small	0,03	0,03
Cars, cng hybrid, small	0,30	0,29
Cars, h2 hybrid, small	0,21	0,19
Cars, battery, small	0,47	0,44
Cars, h2 fc, small	0,57	0,53
Cars, dsl., medium	0,00	0,00
Cars, gsl., medium	0,27	0,23
Cars, cng, medium	0,51	0,46
Cars, h2 ice, medium	0,41	0,36
Cars, dsl. hybrid, medium	0,02	0,02
Cars, gsl. hybrid, medium	0,27	0,24
Cars, cng hybrid, medium	0,50	0,47
Cars, h2 hybrid, medium	0,41	0,37
Cars, battery, medium	0,65	0,60
Cars, h2 fc, medium	0,67	0,61
Buses, diesel	0,00	0,00
Buses, diesel hybrid	0,12	0,12
Buses, cng	0,40	0,30
Buses, h2 fuel cell	0,12	0,07
Buses, battery	0,31	0,21

Here, we first compare the different technologies in their BAU specification, this is including taxes that do not necessarily correspond to environmental costs. The values provided in Table 21 express the monetized difference between the technologies (using the willingness-to-pay (see Table 4) to valuate non-monetary car properties). This value covers all differences between the technologies as observed by the consumer under the BAU scenario: prices, taxes but also differences in available luggage space, etc. The unit is € per vkm (vehicle kilometre) and the value of the most attractive technology has been normalized to zero. It are these values that drive the technology choice in the BAU scenario. A value higher than zero represents a cost disadvantage per vkm.

Table 22: external damage cost from emissions in €2000 per ton

pollutant	*region*	*1994*	*2000*	*2010*	*2020*
CO	Brussels	3,15	3,15	3,15	3,15
CO	Other urban	3,15	3,15	3,15	3,15
CO	Rural	0,83	0,83	0,83	0,83
NO_X	Brussels	5000	6600	8700	9400
NO_X	Other urban	5000	6600	8700	9400
NO_X	Rural	5000	6600	8700	9400
PM	Brussels	911572	911572	911572	911572
PM	Other urban	308580	308580	308580	308580
PM	Rural	102860	102860	102860	102860
C_6H_6	Brussels	2546	2546	2546	2546
C_6H_6	Other urban	654	2546	2546	2546
C_6H_6	Rural	654	654	654	654
NMVOC	Brussels	1100	1100	1100	1100
NMVOC	Other urban	1100	1100	1100	1100
NMVOC	Rural	1100	1100	1100	1100
CH_4	Brussels	45	45	45	45
CH_4	Other urban	45	45	45	45
CH_4	Rural	45	45	45	45
SO_2	Brussels	10975	12349	13042	13135
SO_2	Other urban	10975	12349	13042	13135
SO_2	Rural	5623	6996	7689	7783
CO_2	Brussels	20	20	20	20
CO_2	Other urban	20	20	20	20
CO_2	Rural	20	20	20	20

In a next step, we define a sustainability indicator which covers the full social costs of the different technologies: including resources costs, physical properties (e.g. available luggage space) and environmental costs but excluding taxes. The environmental costs have been calculated making use of the external cost values discussed in §5.1.1 (see Table 22), the emissions are calculated ex-post for new cars making use of the methodology described in §5.1.1. Again we normalize the value of the most attractive technology to zero. The difference between the technologies now expresses a difference in sustainability: it does reflect the full social cost of the technologies.

We should stress again that the implementation of "sustainability" here is different from the approach applied in Task A (chapter 3) and hence results may differ.

For medium private cars, we observe that the diesel car gets the best sustainability score. At first sight this may look odd and not in line with conclusions of task A (see §3.2). The explanation for the good score of diesel private cars is in the value of the diesel dummy coefficient in the choice model. The higher environmental cost of diesel private cars (see Figure 31) does not outweigh the observed preference for diesel cars.
The importance of the diesel dummy becomes even clearer if we examine small private cars where we assumed a negative coefficient instead of the positive value observed for medium diesel cars: here the gasoline car gets the best score.
The hybrid cars generally get a very similar score as their conventional counterparts, whereas battery and fuel cell cars seem to be the least attractive both under BAU and sustainable specifications.

We should however draw the attention here to the differences between the BAU scenario choice determinant and the sustainability indicator. If we look to medium private cars, we observe that the difference between diesel and gasoline is smaller for the sustainability indicator. This means that although diesel cars are "on average" preferred over gasoline cars both in the BAU-scenario and in the sustainability setting, the share of diesel cars would be smaller if we take into account full social costs of the technologies.

Studying the difference between conventional and hybrid technologies, we observe that in the BAU setting the preference seems to go rather to the hybrid: elevated taxes on fuels make these more fuel efficient technologies attractive over their conventional counterparts. However, if we omit taxes and look to environmental damage only, hybrid cars lose their advantage and become slightly less preferred than their counterparts who are cheaper in purchase cost. The main story here is that fuel taxes are higher than environmental damage related to fuel consumption (CO_2 emissions).

4.1.3.5 Sustainability of modes

The modal choice in TREMOVE is modelled making use of a CES utility function specification. This makes the comparison of modes less straightforward as in the logit setting used for technology choice.

We limit ourselves here to a comparison of the current tax with the environmental damage. This provides an indication of the direction in which a sustainable modal shift may be considered: from modes where taxes are smaller than environmental costs towards modes that already have a tax level above the damage caused.

The environmental costs do however cover only part of the external damage caused. A more complete discussion of social cost of transport modes would have to consider e.g. external congestion costs which fall beyond the scope of this study.

Table 23: BAU 2020 Comparison of urban modi (0,01€ per pkm or tkm)

mode	*environmental cost*	*tax*
Private car (small)	0,3	7,7
Private car (large)	0,9	8,5
Bus	0,3	-0,1
Rail	0,0	-4,3
Motorcycle	0,4	6,4
Non-motorised	0	0
LDV	3,8	6,5
HDV	2,5	5,2

Table 24: BAU 2020 Comparison of non-urban modi (0,01€ per pkm or tkm)

mode	*environmental cost*	*tax*
Private car (small)	0,2	6,5
Private car (large)	0,3	7,5
Bus	0,3	-0,7
Rail	0,2	-2,3
Motorcycle	0,4	6,6
LDV	1,4	4,0
HDV	0,4	1,2
Freight train	0,2	0,0
Inland waterways	0,5	0,4

We observe that for road modes (except buses), taxes are higher than environmental costs, whereas for buses and non-road modes taxes are lower. Based on this observation, a shift towards non-bus road modes seems advisable. At first sight this may look odd: rail modes cause less environmental damage which is reflected in the environmental cost figures, a shift away from them would mean more environmental damage. The rationale for advocating a shift towards "overtaxed" modes is that the current taxes keep people from using them to a degree that is higher than could be defended from an environmental point of view.

We should however emphasize that this representation does not fully explain the CES modelling framework dynamics and only provides an indication of a possible sustainable shift. In the scenarios, the main focus will be on technology shift rather than on modal shift.

4.2 TEMAT business-as-usual CES (Task A, B, D)

4.2.1 Transport activity

In scenario BAU TEMAT CES, data related to vehicle stock, penetration of technologies and traffic figures (vehicle kilometres, ton km, passenger km, traffic type, speed, …) correspond to figures in BAU TREMOVE CES (see paragraph 4.1.1).

4.2.2 Technological specification

The penetration of the different technologies in BAU TEMAT CES corresponds to the penetration degrees in BAU TREMOVE CES (see paragraph 4.1.2).

However, the emissions related to the different technologies are assessed applying the TEMAT emission module of VITO (see paragraph 2.4 and 4.3.2).

4.2.3 Damage cost per tonne emissions

For the used damage costs per tonne emission we refer to section 2.5 and Table 11.

4.2.4 Direct and indirect emissions

The bars in Figure 13 to Figure 17 show the evolution of the emissions (CO_2eq, NO_x, NMVOC, SO_2 and PM) at vehicle level under the BAU scenario of CES. In the figures a distinction is made between road transport, rail transport and inland navigation. The black line in the figures shows the total emissions under BAU CES, this is the sum of the emissions at vehicle level and the emissions during the production of the fuel and the production of electricity.

Figure 13 to Figure 17 also show the results of the BAU scenario of VITO (areas). The differences with BAU TEMAT CES are discussed in paragraph 4.4. The grey line shows the total emissions under BAU VITO taking into account the emissions during the production of the fuel and the production of electricity.
We also added the national emission ceilings to the graphs (see paragraph 4.2.4.1)

4.2.4.1 European directive upon national emission ceilings (EC/2001/81)

Within the Directive EC/2001/81 NO_x, NMVOC, SO_2 and NH_3 emission ceilings for 2010 are set for transport. The emission ceilings are given in Table 25, NH_3 is not mentioned as we did not pay attention to this pollutant in the current study. The ceilings count for the whole transport sector, thus also off-road. Within SUSATRANS we did not study the whole off-road sector, only rail traffic and inland navigation were incorporated. So, checking the results of SUSATRANS with the emission ceilings, could lead to too optimistic figures. Therefore, we took into account emissions calculations by IIASA for off-road (see Table 25). The rough IIASA data upon ocean shipping resulted in 2,9 kton SO_2, which is far beyond the SO_2 emission ceiling. Within its assessment IIASA worked with 2,5 weight percent sulphur in heavy fuel. By 2010 annex VI of the MARPOL convention will be applied resulting in the use of 1,5 weight percent sulphur in heavy fuel. So, VITO adjusted the SO_2 emissions from ocean shipping to this annex VI. Even with this adjustment, Table 25 shows that the share of off-road amounts the SO_2 emission ceiling for 2010.

Table 25: NEC directive transport and estimated emissions "off-road" by IIASA

In kton	NO_x	NMVOC	SO_2
NEC Transport Belgium	68	35,6	2,0
Off-road* IIASA 2010	20,7	9,8	2,1
Remaining for road, rail and inland navigation	47,3	25,8	-0,1

* off-road not taken into account rail traffic and inland navigation and adjusted for ocean shipping to annex VI MARPOL

4.2.4.2 Greenhouse gases

Figure 13 shows the emissions of CO_2 equivalents (=CO_2eq), this represents the sum of CO_2, methane (CH_4) and N_2O emissions taking into account following greenhouse potentials: CO_2 = 1, CH_4 = 23 and N_2O = 296.

The direct emissions (vehicle level) of CO_2eq under the BAU scenario of CES (bars) increase from about 17,6 mega tonne (Mton) in 2000 to 19,8 Mton in 2020. This is an increase by 13 %. The grow rates seem to decrease in the 21st century. Road transport is responsible for 97 to 98 % of the total direct emissions of CO_2eq (road, rail, waterway).

In Belgium there is no specific target deduced from the Kyoto Protocol for CO_2eq emissions from transport. The Flemish Region sets within the MINA-plan 3 a stabilisation of the CO_2 emissions from transport in 2010 at the level in 1990. This stabilisation target was stated in the Flemish Transportation Plan, which was the result of the strategic environmental assessment of the draft Transportation Plan. Within SUSATRANS we check the feasibility of this target at the Belgian level. As TREMOVE gives figures from 1995 on, we take the CO_2 trend 1990-1995 from BAU VITO (see annex V). There is a continuous increase of CO_2 emissions from transport in the period 1990-1995. Under the BAU CES direct emissions of CO_2eq increase with about 16 % in the period 1995-2010. We could conclude that under the BAU scenario a stabilisation of the CO_2 emissions in 2010 at the level of 1990 will not be attained.

The total emissions (inclusive indirect emissions) of CO_2eq under the BAU CES (black line) increase from about 20,7 Mton in 2000 to 24,7 Mton in 2020. This is an increase of 19 %, which is higher than the 13 % for direct emissions. This could mainly be explained by the increase of energy needed to exploit crude oil at less and less accessible places. Also the closure of nuclear plant results in higher greenhouse gas emissions during the production of electricity. The introduction of electrical (battery) cars and fuel cell vehicles influences the indirect emissions only in a small extent, because of their low penetration degree. Although in the distant future they could be important, as per mega joule electrical energy produced, emissions of CO_2eq are about 6 to 10 times higher compared to one mega joule diesel and gasoline. Fuel cell cars result in higher CO_2eq emissions as we assumed that in the time horizon until 2020 hydrogen will be produced from natural gas. Compared to the production of diesel and gasoline, hydrogen produced from natural gas gives 6 to 7 time more CO_2eq during the production process.

In the late nineties, the indirect emissions account for 15 to 16 % in the total CO_2eq emissions from transport, in 2020 this will be 20 %. This could be explained by the high introduction rates of alternative motor vehicles under the BAU scenario of CES.

4.2.4.3 Nitrogen oxides

Figure 14 shows that direct emissions (vehicle level) of NO_x under the BAU scenario of CES (bars) decrease from about 106 kilo tonne (kton) in 2000 to 49 kton in 2020. This is a decrease by 54 % in 20 years, mainly due to more stringent European emission regulations for new road vehicles in the period 1993-2009. In 2000 road transport was responsible for 93 % of the total direct NO_x emissions (road, rail, waterway). By 2020 the share of road transport in the NO_x emissions will decrease to 80 %, mainly due to the very stringent emission limits for heavy duty vehicles (trucks and busses) in 2005 (euro 4 emission limits) and 2009 (euro 5), and the decrease of diesel cars after 2010 in favour of alternative motor vehicles under BAU CES.

Comparing the 2010 NO_x emission level to the international commitment on NO_x (red line in Figure 14) and taking into account the correction for off-road emissions (Table 25), we could conclude that the NO_x emission ceiling is not reached.
The total emissions (inclusive indirect emissions) of NO_x under the BAU CES (black line) decrease from about 116 kton in 2000 to 60 kton in 2020. This is a decrease by 48 %, which is lower than the 54 % for direct emissions. This is mainly explained by the fact that the NO_x emission per mega joule energy produced remains constant during 2000-2020, whereas there is a sharp decrease in NO_x direct emissions. To a much less extent, the introductions of electrical (battery) cars and fuel cell vehicles intensify the difference. Per mega joule electrical energy produced emissions of NO_x are about three times higher compared to one mega joule diesel and gasoline. Fuel cell cars result in higher indirect NO_x emissions than diesel and gasoline as we assumed that in the time horizon until 2020 hydrogen will be produced from natural gas. Compared to the production of diesel and gasoline, hydrogen produced from natural gas gives twice as much NO_x emissions during the production process.

In 2000 the indirect emissions account for 8 % of the total NO_x emissions from transport, in 2020 this will be 18 %.

4.2.4.4 Non methane volatile compounds

Figure 15 shows that direct emissions (vehicle level) of NMVOC under the BAU scenario of CES (bars) decrease from about 51 kton in 2000 to 22 kton in 2020. This is a decrease by 57 % in 20 years, mainly due to more stringent European emission regulations for new road vehicles in the period 1993-2009. Road transport is responsible for about 97 % of the total direct NMVOC emissions (road, rail, waterway).

In 2010 the NMVOC emission level lies far below the national ceiling (red line in Figure 15) corrected for the emissions from off-road transport (Table 25).

The total emissions (inclusive indirect emissions) of NMVOC under the BAU CES (black line) decrease from about 76 kton in 2000 to 43 kton in 2020. This is a decrease by 44 %, which is lower than the 57 % for direct emissions. This is mainly explained by the high share of indirect NMVOC in the total emissions in 2000 (33 %) and the fact that the NMVOC emission per mega joule remains constant during 2000-2020 whereas there is a sharp decrease in direct NMVOC emissions, due to European legislation upon new vehicles. Therefore, the share of indirect emissions rises up to 48 % by 2020.

4.2.4.5 Sulphur dioxide

Figure 16 shows that direct emissions (vehicle level) of SO_2 under the BAU scenario of CES (bars) decrease from about 2,5 kton in 2000 to 0,2 kton in 2020. This is a decrease by 92 % in 20 years, mainly due to the European regulation on sulphur content in gasoline and diesel for motor vehicles. In 2000 road transport was responsible for 82 % of the total direct SO_2 emissions (road, rail, waterway). By 2020 the share of road transport in the SO_2 emissions will decrease to 57 %, mainly due to European fuel specifications becoming very severe on sulphur content for road transport and the high share in alternative motor fuels under BAU CES. In 2020 the share of inland navigation in the SO_2 emissions will be 39 %.

After we corrected the national SO_2 ceiling for transport for emission by off-road transport (Table 25), we saw a small exceeding of the SO_2 target. In reality sulphur content in fuels are generally somewhat lower than prescribe by the legislations. So, it could still be possible to reach SO_2 commitment for the transport sector as a whole (inclusive off-road).

The total emissions (inclusive indirect emissions) of SO_2 under the BAU CES (black line) decrease from about 18 kton in 2000 to 16 kton in 2020. This is a decrease by 8 %, which is much lower than the 92 % for direct emissions. This is mainly explained by the high share of indirect SO_2 in the total emissions in 2000 (86 %) and the fact that the SO_2 emission per mega joule remains constant during 2000-2020 whereas there is a sharp decrease in direct SO_2 emissions. Therefore the share of indirect emissions rises up to 99% by 2020.

4.2.4.6 Particulate matter

Figure 17 shows that direct emissions (vehicle level) of PM under the BAU scenario of CES (bars) decrease from about 5,5 kton in 2000 to 1,6 kton in 2020. This is a decrease by 71 % in 20 years, mainly due to more stringent European emission regulations for new road vehicles in the period 1993-2009. In 2000 road transport was responsible for 94 % of the total direct PM emissions (road, rail, waterway). By 2020 the share of road transport in the PM emissions will decrease to 78 %, mainly due to the more stringent PM emission limits for diesel vehicles, and the decrease of diesel cars after 2010 in favour of alternative motor vehicles.

Until now neither international nor national targets have been set for PM emission levels.

The total emissions (inclusive indirect emissions) of PM under the BAU CES (black line) decrease from about 5,9 kton in 2000 to 2,0 kton in 2020. This is a decrease by 66 %, which is lower than the 71 % for direct emissions. This is mainly explained by the constant PM emission factors for the calculation of indirect emissions, whereas for direct emissions we see a sharp decrease in emission factors from 2000-2020. Furthermore the introduction of electrical (battery) cars increase the amount of indirect emissions as PM emissions during the production of 1 mega joule electrical energy produced emissions of PM are about three to eight times higher compared to one mega joule diesel and gasoline.

In 2000 the indirect emissions account for 7 % of the total PM emissions from transport, in 2020 this will be 19 %. The same explanation applies here as for the evolution in total PM emissions.

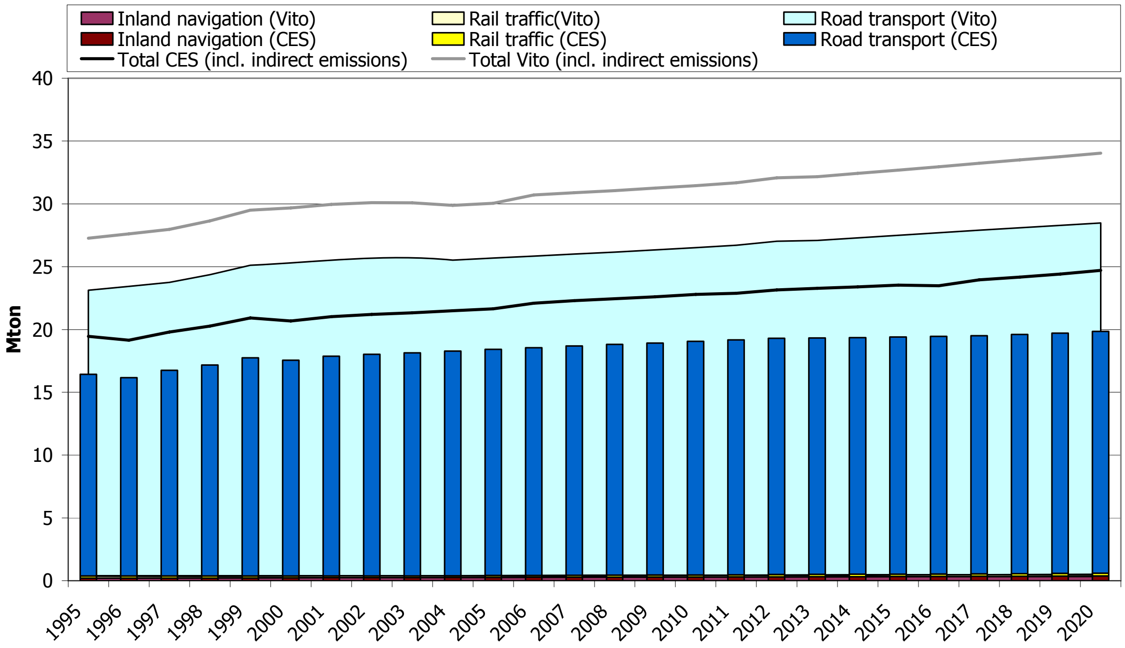

Figure 13: evolution of the total CO_2eq emissions from transport in Belgium under BAU CES (bars and black line) and BAU VITO (areas and grey line)

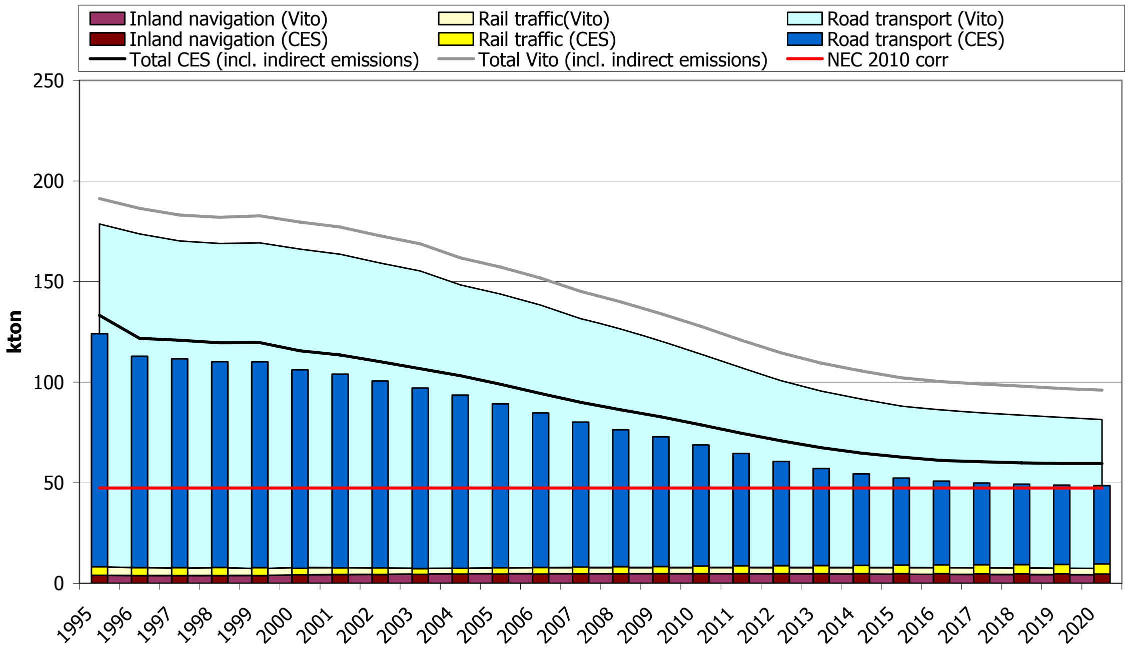

Figure 14: evolution of the total NO_x emissions from transport in Belgium under BAU CES and BAU VITO

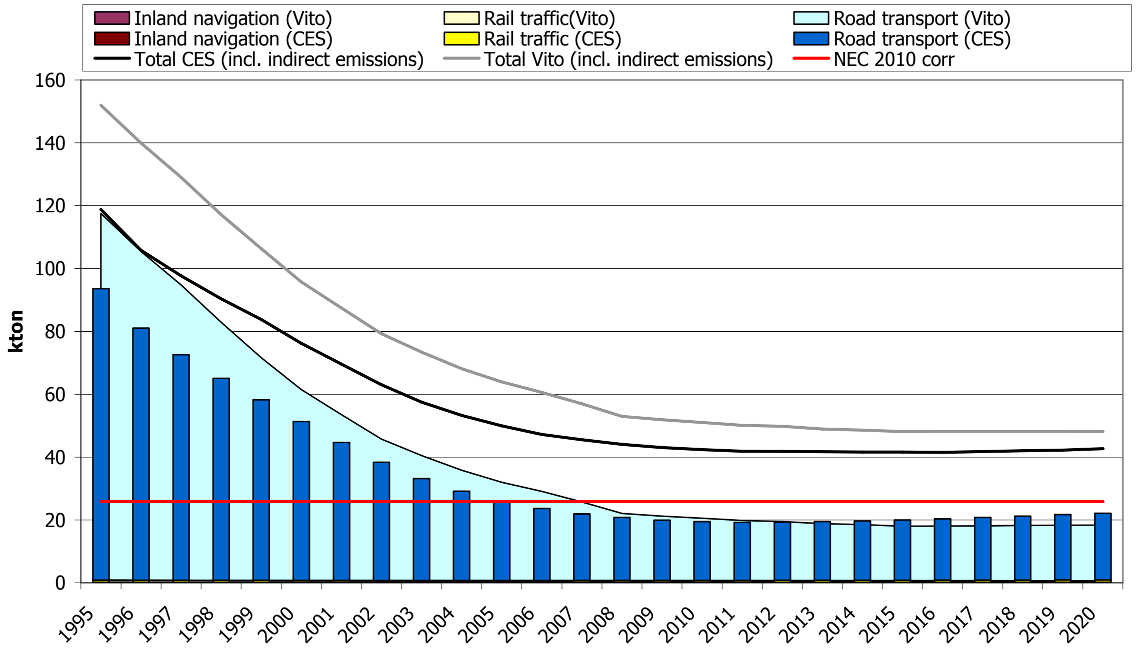

Figure 15: evolution of the total NMVOC emissions from transport in Belgium under BAU CES and BAU VITO

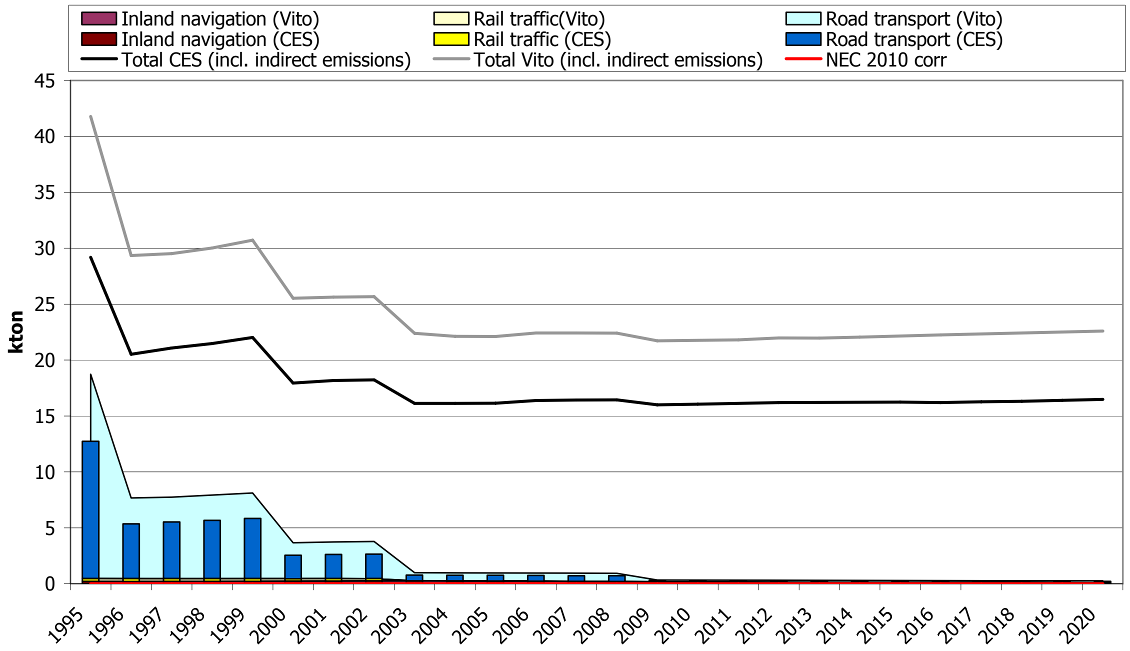

Figure 16: evolution of the total SO_2 emissions from transport in Belgium under BAU CES and BAU VITO

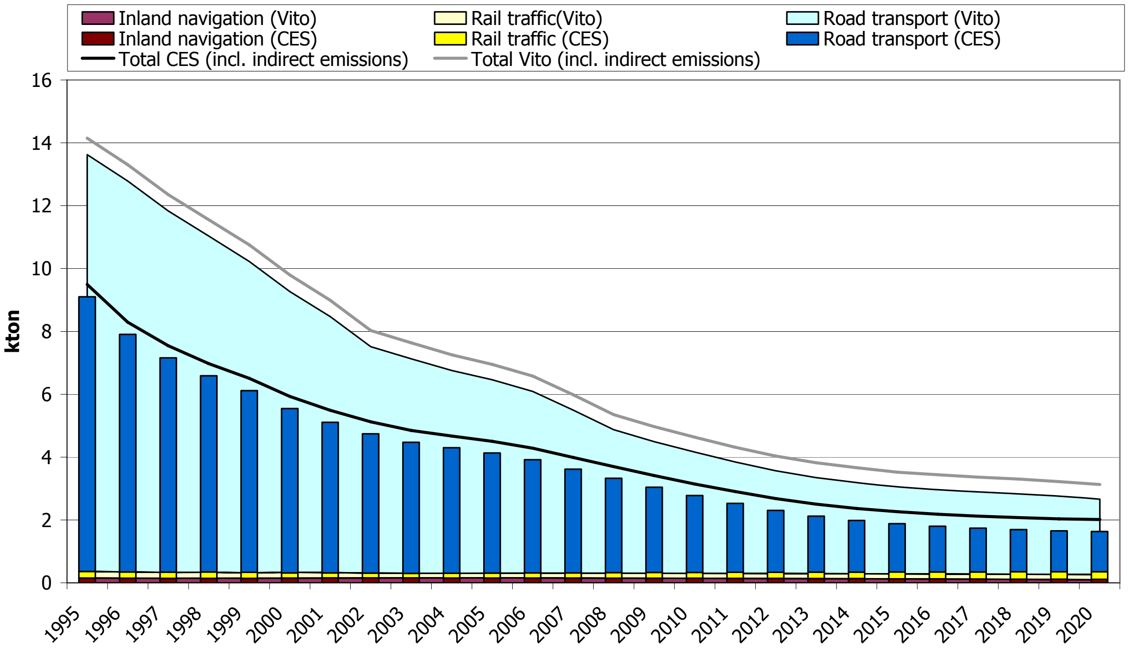

Figure 17: evolution of the total PM emissions from transport in Belgium under BAU CES and BAU VITO

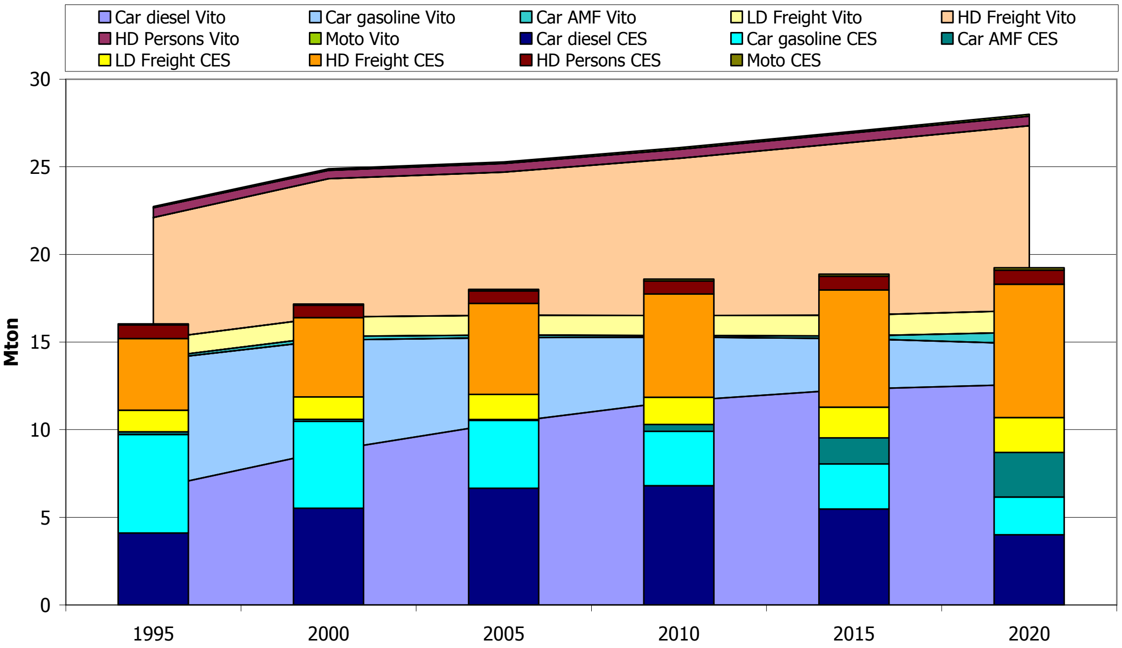

Figure 18: direct CO_2eq emissions from road transport in Belgium per vehicle category under BAU CES (bars) and BAU VITO (areas)

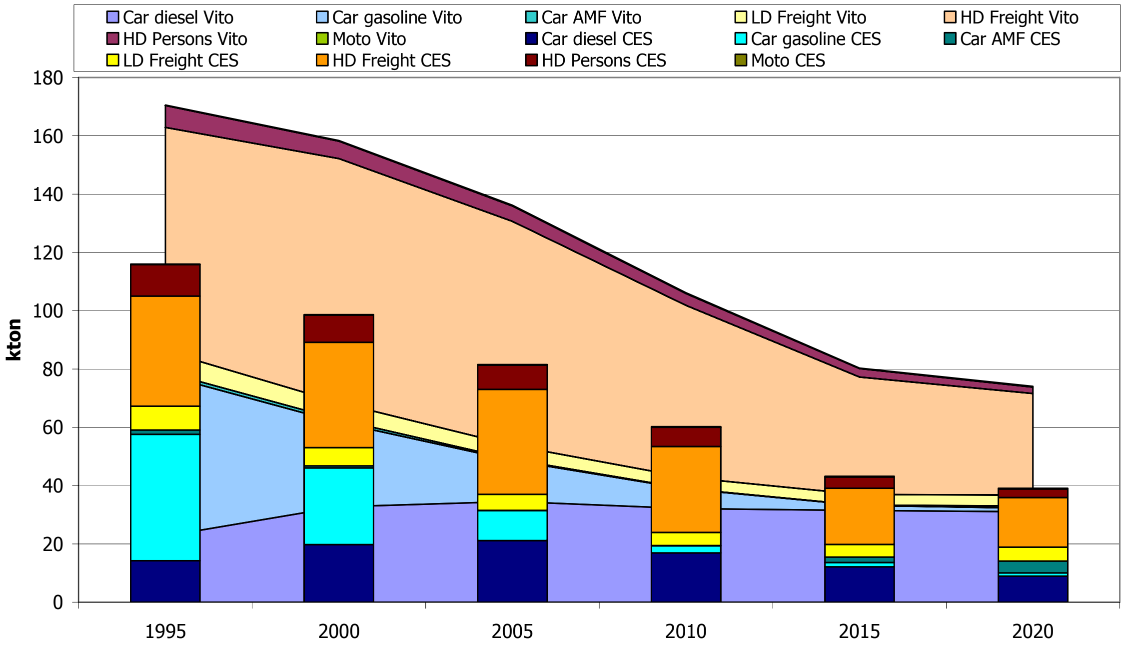

Figure 19: direct NO_x emissions from road transport in Belgium per vehicle category under BAU CES (bars) and BAU VITO (areas)

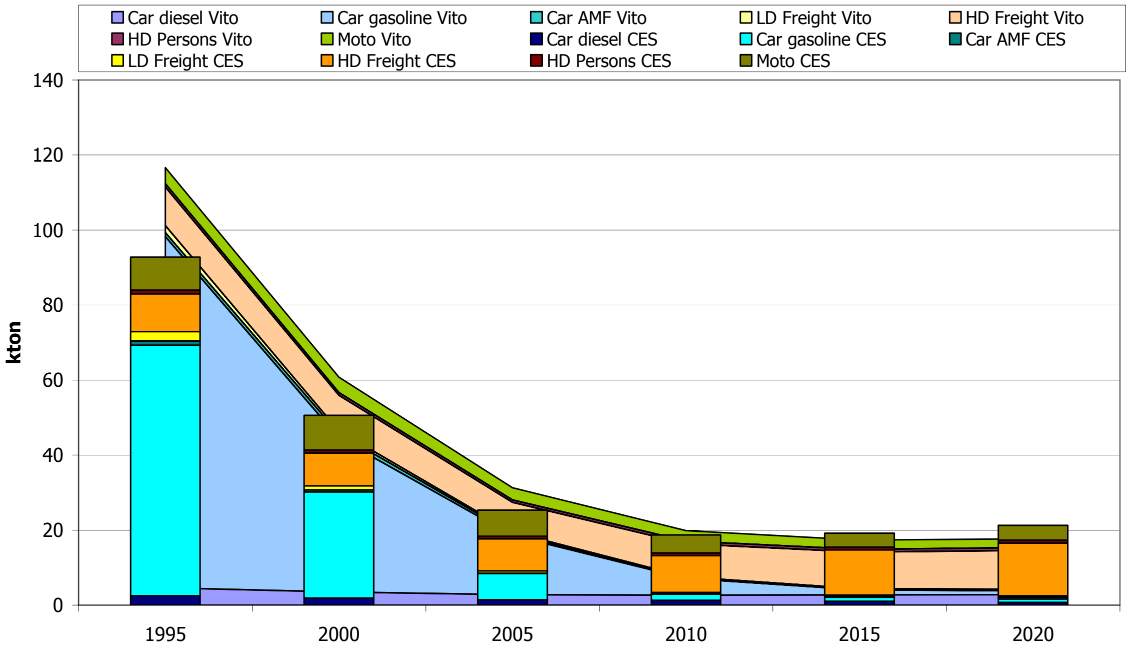

Figure 20: direct NMVOC emissions from road transport in Belgium per vehicle category under BAU CES (bars) and BAU VITO (areas)

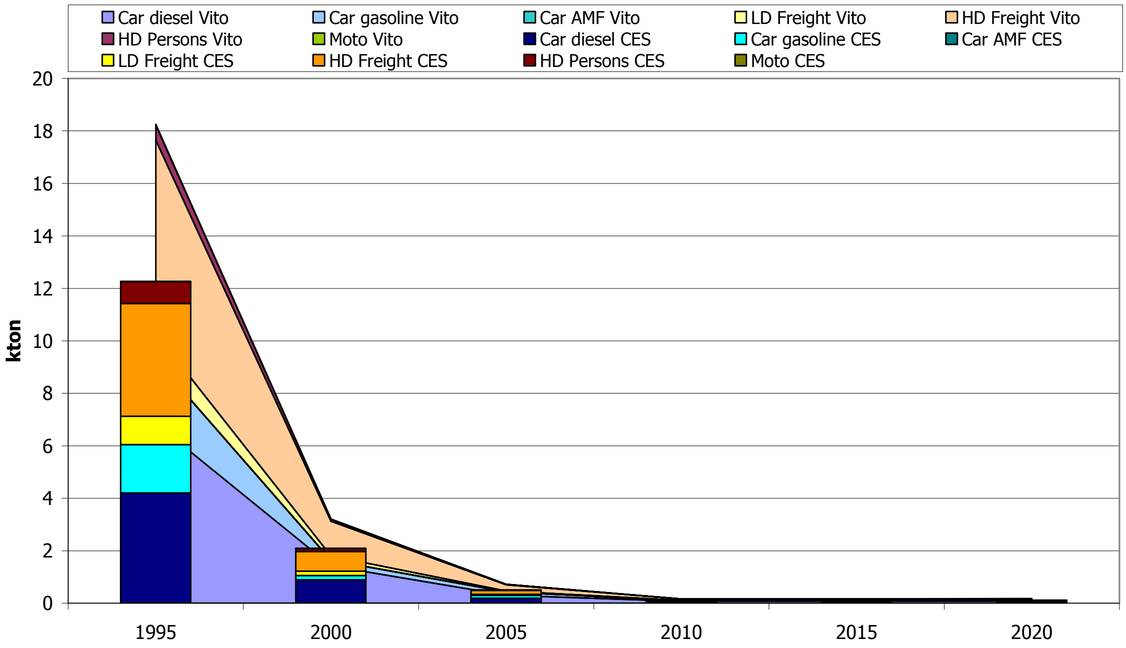

Figure 21: direct SO_2 emissions from road transport in Belgium per vehicle category under BAU CES (bars) and BAU VITO (areas)

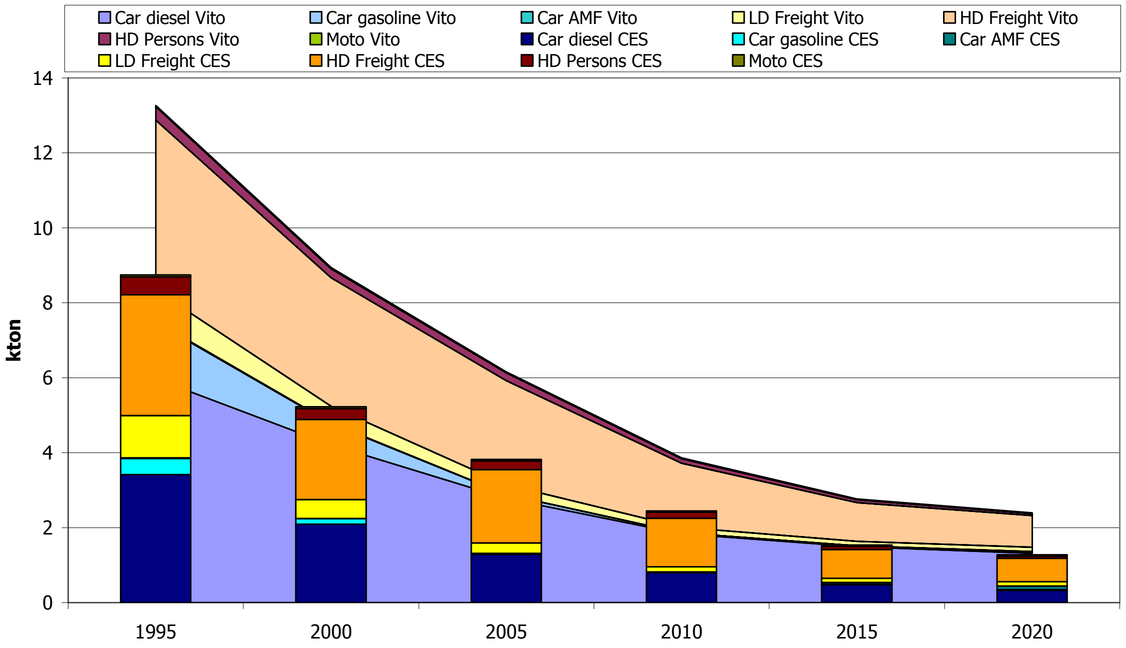

Figure 22: direct PM emissions from road transport in Belgium per vehicle category under BAU CES (bars) and BAU VITO (areas)

4.2.5 Direct emissions from road transport

In this section we discuss more in detail the direct emissions from road transport as this remains the main source of the emissions of greenhouse gases, NO_x, NMVOC, SO_2 and PM within transport in Belgium (road transport, rail traffic, inland navigation).

The bars in Figure 18 to Figure 22 show the evolution of the direct emissions (at vehicle level) of road transport in Belgium under the BAU scenario of CES. In the figures a distinction is made between diesel car, gasoline car, car on an alternative motor fuel (AMF), light duty freight (LD), heavy duty freight (HD) and motorcycle (moto). In the figures emissions are given in five years intervals starting from 1995 (reference year TREMOVE) and ending in 2020. However, in the text emissions in 2020 are mostly compared to the emissions in 2000.

Figure 18 to Figure 22 also show the results of the BAU scenario of VITO (areas). The differences with BAU TEMAT CES are discussed in paragraph 4.4 (comparison).

4.2.5.1 Greenhouse gases

Figure 18 shows the emissions of CO_2eq. Under BAU CES (bars), greenhouse gas emissions from road transport increase by 12 % from 2000 to 2020. The growth was more pronounced between 1995-2000. This downwards evolution is attributed to the decrease in greenhouse gases emitted by the passenger car fleet, this is due to:

- the agreement of the European Commission and the automotive industries to reduce average CO_2 emission from new cars;
- the continuous growth in preference for diesel vehicles by Belgian consumers instead of gasoline;
- the high penetration degree of AMF cars under BAU CES after 2010.

Greenhouse gas emissions from road freight transport continuously grow in the period 1995-2020. Their share rises from 33 % in 1995 to 50 % in 2020.

4.2.5.2 Nitrogen oxides

Under BAU CES, Figure 14 gives a decrease by 60 % of the NO_x emissions from road transport in the period 2000-2020. The European emission regulation for new vehicles is responsible for this strong decline. Initially an even stronger effect was expected, but adverse factors being of importance are:

- the growth in activity of mobility within freight road transport (vehicle kilometres);
- the fact that in real traffic NO_x emission factors of euro 2 and euro 3 heavy duty vehicles are much higher than could be expected from the regulation;
- the growing preference for diesel cars when buying a new vehicle.

4.2.5.3 Non methane volatile compounds

Under BAU CES, Figure 20 gives a decrease by 58 % of the NMVOC emissions from road transport in the period 2000-2020. The European emission regulation for new vehicles account for this strong decline. From 1993 on (91/441/EC), gasoline cars were equipped with a three way catalyst reducing NMVOC emissions by more than 90 % compared to a non catalyst gasoline cars.

The share of passenger cars in the NMVOC from road transport decreases from 76 % in 1995 to 10 % in 2020. For road freight traffic the share rises from 14 % to 68 %. The share of motorcycles in NMVOC emissions increases from 10 % in 1995 to 18 % in 2020.

4.2.5.4 Sulphur dioxide

Figure 21 shows a decrease by 94 % of the SO_2 emissions from road transport in the period 2000-2020. This evolution is due to the more stringent European regulation on sulphur content in gasoline and diesel fuels for road vehicles. Compared to the emission regulation for new vehicles, the regulation for gasoline and diesel fuels has an abrupt decline in emissions as it affects the whole road vehicle fleet immediately.

4.2.5.5 Particulate matter

Under BAU CES, Figure 22 gives a decrease by 76 % of the PM emissions from road transport in the period 2000-2020. The European emission regulation for new vehicles account for this strong decline.

4.3 TEMAT business-as-usual VITO (Task A, D)

There were different reasons for VITO to design its own BAU scenario:
- In 2004 we upgraded the emission model TEMAT and we performed a validation for the historical years (1990-2003). The total fuel consumption figures per energy vector were tuned to the national fuel sales (annex V);
- For passenger cars the BAU scenario defined by CES shows optimistic introduction rates for alternative fuels and motor technologies. This could affect the emission trends set by the BAU scenario of CES;
- TREMOVE is not a forecasting tool, but TEMAT is;
- Working with two plausible assumptions could give an indication on the uncertainty range.

4.3.1 Transport activity

For road transport VITO made forecasts for total vehicle kilometres based on historical trends derived from statistics for the last five years [38]. We took the sum of the evolution in the three regions, see Figure 23. This figure also plots the total road vehicle activity under BAU CES and BAU IFEU [83].

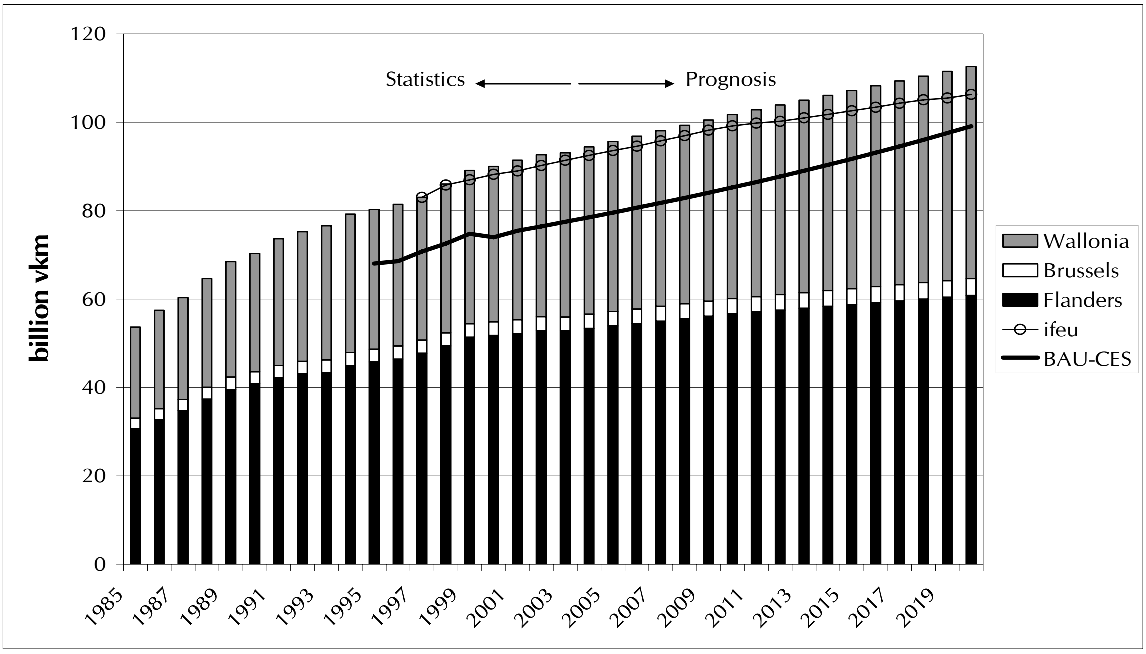

Figure 23: forecasts of vehicle kilometres from road transport in Belgium under BAU scenarios defined by different institutes

The total height of the bars (sum of three regions) shows the amount of vehicles kilometres driven by road transport under BAU VITO. Figure 23 shows that the amount of vehicles kilometres driven under BAU CES are about 16 % below BAU VITO. It seems that national and international statistical data for road vehicles kilometres in Belgium are not well tuned to one another. However, the evolution from 2000 until 2020 in both BAU scenarios matches quit well.

In absolute values BAU VITO is very close to the BAU IFEU until 2010, afterwards IFEU shows a less pronounced growth.

For railway traffic we took into account a further annual increase of passenger traffic by 1,2 to 1,4 %. For Freight transport we assumed a stabilisation of the traffic from 2004 on [84].

For inland navigation we assumed an annual increase of transport by about 2 % until 2020 [84]. This results in an evolution that fits well with BAU CES until 2010, afterward there is a stronger growth in BAU CES.

4.3.2 Technological specifications

Rise in market share of diesel cars

In Belgium the consumer prefers a diesel fuelled vehicle when buying a new passenger car. In 1990 about 34 % of the new cars were diesel fuelled. In 2000 and 2003, this was respectively 55 % and 65 %. VITO assumed a further increase up to 75 % in 2010, afterwards this level stays constant but also takes into account hybrid diesel-electric.

Agreement to reduce CO_2 from new cars

The agreement of the European Commission and the automotive industries to reduce the average fleet CO_2 emission from new cars to 140 g/km in 2008/2009 was partially integrated in the calculation. Also the target of 120 g /km – now under discussion as not feasible – was taken into account. VITO assumed that these targets are fulfilled for about 50 % and even less when taking into account the energy use (~CO_2) needed for the air conditioning in cars [85], see Figure 24.

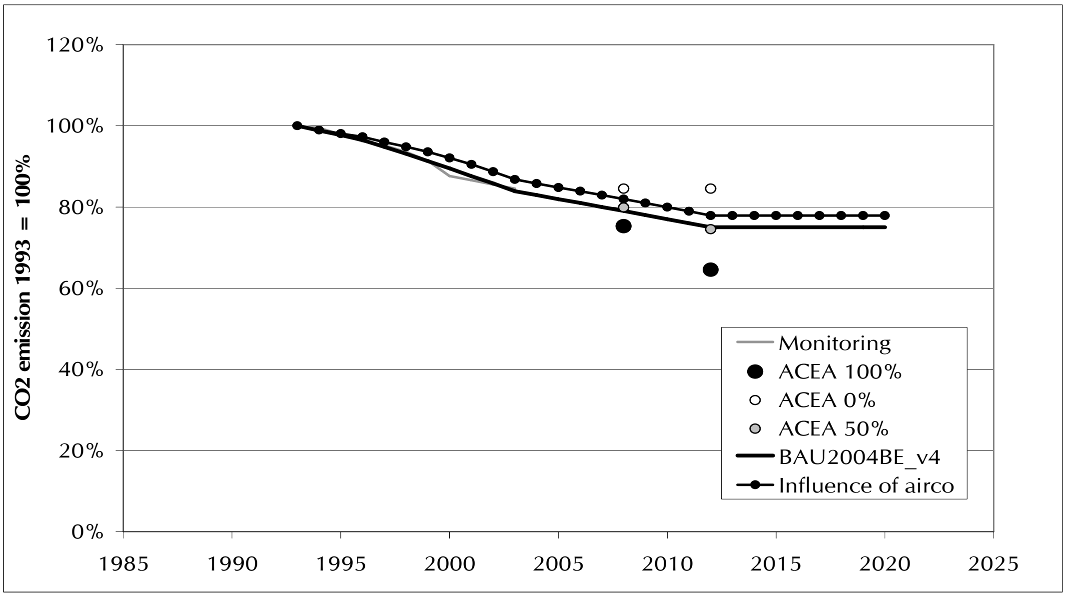

Figure 24: assumptions on CO_2 emissions from new passenger cars and effect of air conditioning

Implementation of European directives

For road transport VITO took into account the latest recorded directives (98/69/EC and 1999/96/EC) coming into force in 2005/2006 (euro 4) and in 2009 (euro 5 for heavy duty vehicles only).

For inland ships we also took into account the emission directive (2004/26/EC).

For road transport we assumed that from 2009 on the maximum sulphur content in gasoline and diesel is 10 ppm (2003/17/EC). For historical years we took the sulphur content as measured by Fapetro.

For inland shipping we take into account the introduction of 0,1 mass% sulphur in 2008 (1999/32/EG). For trains with diesel traction we used 47 ppm sulphur from 2003 on [44, 45].

Within the users' committee it was decided not to take into account the directive on biofuels for transport (2003/30/EC).

Introduction of alternative motor fuels

In contrast to CES, VITO defined a conservative scenario, in which only a limited amount of alternative fuels and motor vehicles are introduced within the passenger car fleet, see Table 26. This is in line with the findings by Esto [86], the alternative fuels contact group [87] and Earpa [100].

Table 26: market share of alternative motor fuels in new purchased passenger cars [%]

Fuel/technology	Introduction		2010	2015	2020
	Date	Level [%]			
CNG	Available	~0	~0	~0	~0
Diesel			75	~74	70
Electric	Available	~0	~0	~0	~0
Fuel cell H2	Not	0	0	0	0
Gasoline			24	21	15
H2 ICE	Not	0	0	0	0
Hybrid CNG	2015	< 1	0	< 1	5
Hybrid diesel	2015	< 1	0	< 1	5
Hybrid gasoline	Available	~0	~0	0,5	5
Hybrid H2	Not	0	0	0	0
LPG			0,25	0,25	0,25

4.3.3 Damage cost per tonne emissions

For the used damage costs per tonne emission we refer to section 2.5 and Table 11.

4.3.4 Direct and indirect emissions

The results for direct and indirect emissions under the BAU-scenario TEMAT VITO are shown in Table 27. Figures are given for direct and indirect emissions separately for the years 1990, 2000, 2010 and 2020.

Although absolute figures differ from those obtained under the BAU-scenario TEMAT CES, trends are rather similar. Except for the total amount of greenhouse gas, emissions decrease during the period 1995-2020.

As total direct emissions under BAU TEMAT VITO are higher than under BAU TEMAT CES, NEC-targets for NO_x and SO_2 are neither reached. Even when taking into account the NMVOC emissions from off-road traffic (Table 25), the NMVOC-target is fulfilled under BAU TEMAT VITO.

Table 27: BAU TEMAT VITO: Total direct and indirect emissions (kton)

kton		1990	2000	2010	2020
CO_2eq	direct	20 200	25 300	26 500	28 500
	indirect	3 460	4 390	4 940	5 550
NO_x	direct	182	166	114	81,4
	indirect	10,8	13,5	13,7	14,5
NMVOC	direct	154	61,5	20,5	18,3
	indirect	34,1	34,3	30,5	29,7
SO_2	direct	15,7	3,67	0,31	0,25
	indirect	19,9	21,8	21,4	22,4
PM	direct	15,3	9,27	4,16	2,66
	indirect	0,45	0,53	0,47	0,47

4.3.5 Direct emissions from road transport

Table 28 lists the results for direct emissions from road transport under the BAU-scenario TEMAT VITO. Figures are given per pollutant and vehicle category for the years 1990, 2000, 2010 and 2020. For passenger cars a distinction is made according to fuel type: gasoline, diesel and alternative motor fuels (AMF).

Table 28: BAU TEMAT VITO: Direct emissions (kton) from road transport

kton		1990	2000	2010	2020
CO2eq	Car diesel	5 210	8 800	11 600	12 600
CO2eq	Car gasoline	6 780	6 320	3 640	2 320
CO2eq	Car AMF	120	198	87,3	666
CO2eq	HD Freight	5 770	7 880	8 980	10 500
CO2eq	HD Persons	465	480	509	560
CO2eq	LD Freight	915	1110	1140	1240
CO2eq	Moto	27,5	88	95,1	99,1
CO2eq	Total	19 300	24 900	26 100	28 000
NOx	Car diesel	16,7	32,7	32,1	31
NOx	Car gasoline	73,7	28,9	6,82	1,18
NOx	Car AMF	1,45	0,96	0,07	0,81
NOx	HD Freight	65,6	83,8	59	34,8
NOx	HD Persons	6,66	6	4,06	2,22
NOx	LD Freight	6,97	5,8	3,85	3,71
NOx	Moto	0,07	0,2	0,24	0,26
NOx	Total	171	158	106	74
NMVOC	Car diesel	4,51	3,49	2,64	2,8
NMVOC	Car gasoline	137	41	4,5	0,99
NMVOC	Car AMF	1,3	1,14	0,13	0,15
NMVOC	HD Freight	8,87	9,52	8,84	10,4
NMVOC	HD Persons	0,71	0,75	0,7	0,78
NMVOC	LD Freight	2,39	0,73	0,28	0,26
NMVOC	Moto	1,51	4,05	2,79	2,33
NMVOC	Total	156	60,7	19,9	17,7
SO2	Car diesel	1,58	1,43	0,07	0,08
SO2	Car gasoline	2,27	0,21	0,02	0,01
SO2	Car AMF	0	0	0	0
SO2	HD Freight	1,8	1,32	0,06	0,07
SO2	HD Persons	0,14	0,08	0	0
SO2	LD Freight	0,29	0,17	0,01	0,01
SO2	Moto	0,01	~0	~0	~0
SO2	Total	6,09	3,2	0,16	0,17
PM	Car diesel	5,98	4,21	1,83	1,32
PM	Car gasoline	3,68	0,57	0,03	0,02
PM	Car AMF	0,02	0,01	~0	0,03
PM	HD Freight	4,08	3,43	1,71	0,84
PM	HD Persons	0,31	0,24	0,12	0,05
PM	LD Freight	0,76	0,45	0,15	0,12
PM	Moto	0,01	0,03	0,02	0,02
PM	Total	14,8	8,94	3,86	2,4

Although absolute figures differ from those obtained under the BAU-scenario TEMAT CES, trends are rather similar. AMF vehicles penetrate only to a small extent in the fleet by 2020, so emissions from AMF are minor in 2020.

More information on the results of BAU TEMAT VITO is given in annex V.

4.4 Comparison BAU TEMAT CES to BAU TEMAT VITO

In this section we explain the major differences in emission results between BAU TEMAT CES and BAU TEMAT VITO. By doing so we indicate the uncertainty due to mobility figures (e.g. vehicle kilometre, road type fraction, average speed) and vehicle and technological parameters (e.g. fuel type, weight class).

The differences between the emissions of transport (road, rail waterway) under both BAU scenarios are shown in Figure 13 to Figure 17. However, here we focus on road transport because the contribution of rail traffic and inland navigation is mostly minor compared to road traffic.

The differences between BAU TEMAT CES and BAU TEMAT VITO for road transport are given in Figure 18 to Figure 22. The share of the various vehicle types is given. The emissions from road transport in BAU VITO lie about 10 (NMVOC) to 70 % (NO_x and PM) higher than those in BAU TEMAT CES, although the total vehicle kilometres driven in BAU TEMAT VITO is only 18 % higher than in BAU CES. The total vehicle kilometres driven in BAU CES and BAU VITO are calibrated against different sources [38, 71]. The difference in kilometres driven explains only partly the differences between the emissions in both BAU scenarios.

Further insight in the differences could be found by looking to the figures for the emissions of CO_2eq (Figure 18) and NO_x (Figure 19). The CO_2eq emissions lie about 40 to 46 % higher in VITO BAU. This could not totally be explained by the higher CO_2eq emissions from passengers cars, as they drive about 31 % more in BAU VITO than BAU CES. Although the amount of vehicle kilometres driven by heavy duty freight (HDF) lies about 20 % higher in BAU CES compared to BAU VITO, the emissions from HDF are higher in BAU VITO. An explanation could be found in the segmentation of the trucks over different weight classes. Under BAU CES (output TREMOVE) in the period 1995-2020 only 2 % of the trucks sort under weight class 32 to 40 tonne. Under BAU VITO, this amount is 42 % in 1995 and increases up to 70 % by 2020. In vehicle statistics the combination of truck tractor and trailer is not given (impossible to do). The segmentation of trucks in BAU CES leans on these statistics. This results in about 40 % trucks falling within weight class 3,5 to 7,5 tonne; this is probably an overestimation. In BAU VITO, we tried to adjust the segmentation over the weight classes. Correction was performed based on vehicle statistics and results from traffic counts.

Prognoses of emissions are not only affected by above mentioned uncertainties but also by the share of different motor fuels and technologies in the passenger car fleet. Looking to the amount of vehicle kilometres driven by diesel cars (hybrid included) the amount decreases from 65 to 53 % from 2010 to 2020 under BAU CES, whereas under BAU VITO this is about 80 % over the whole period.

The share of fuels and technologies in the passenger car stock in both BAU scenarios explains the further divergence in emissions from road transport after 2010, see Figure 11 and Figure 25. In BAU CES the vehicle stock in 2010 counts about 54 % diesel cars (hybrid diesel included), whereas VITO counts 60 % diesel cars (hybrid diesel included). In 2020 the share is respectively about 42 % and 70 %. Looking to alternative motor fuels and technologies (AMF), hybrid diesel and gasoline excluded, AMF vehicles account for more than 24 % in BAU CES and only 1 to 2 % in BAU VITO. When taking into account hybrid diesel and hybrid gasoline, the share increases respectively to more than 45 % in BAU CES and only 5 % in BAU VITO.

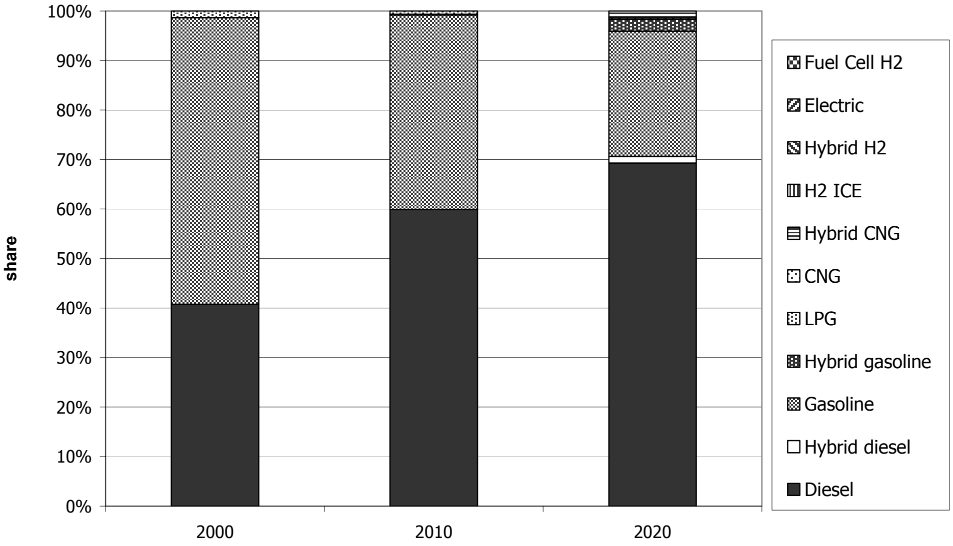

Figure 25: private car stock composition in BAU scenario TEMAT VITO

Also, traffic related parameters (average speed, road type fraction, traffic type fraction) effect the emissions. Figure 26 shows the average speeds for motorway and rural traffic for off peak and peak traffic in BAU CES and BAU VITO. Speeds during rush hours are higher under BAU CES.

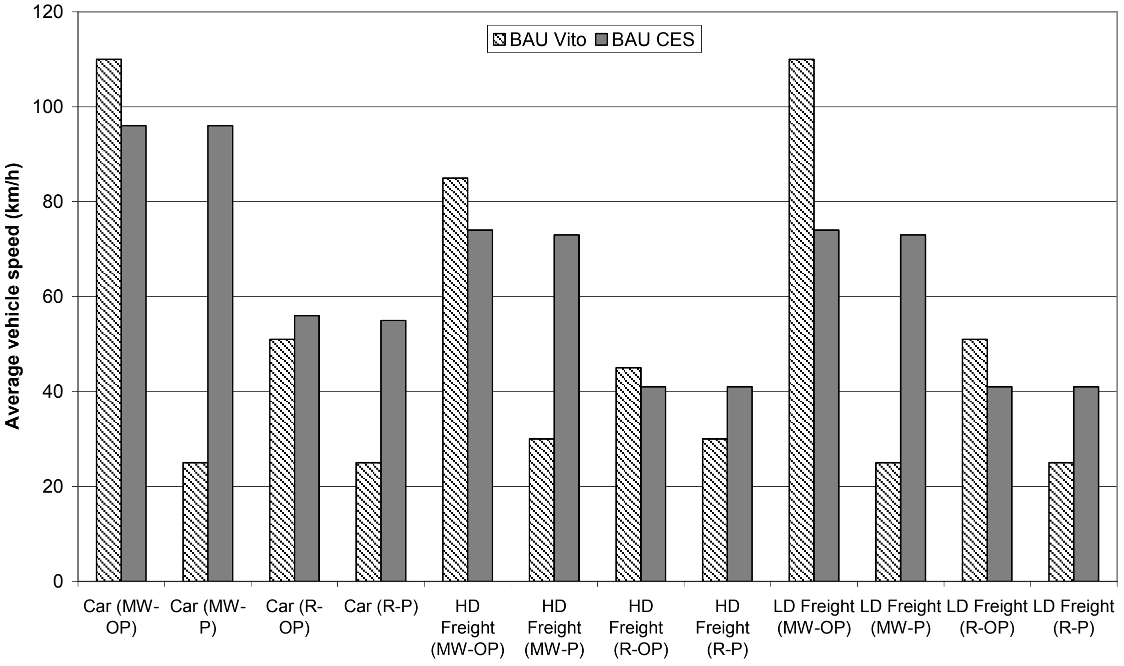

Figure 26: comparison of average speeds in BAU CES and BAU VITO (MW = motorway, R = rural, OP = off peak, P = peak)

There are al lot of differences between BAU CES and BAU VITO due to a different methodology, input data and uncertainties. This makes that although the same emission functions were used in both scenarios, fleet emission factors (g/km) could differ to some extent, see Table 29. A fleet emission factor is an average emission per kilometre driven in a specified year. Here we make a distinction between vehicle type and motor fuel technology. Only direct emissions (at vehicle level) are taken into consideration. If the tables give no values it means that this vehicle option is not in the scenario. If the value is zero, it means that there is no exhaust emission at vehicle level.

In general, we could conclude that the fleet emission factors are lower under BAU CES. This is mainly due to differences in traffic related data, such as higher average speeds during peak traffic. For some fuels, differences are enhanced due to the earlier introduction of cleaner technologies (e.g. CNG cars and hybrid gasoline-electric cars). Differences are the biggest for heavy duty freight, about a factor two lower in BAU CES. This mainly is due to the different segmentation in weight classes.

Table 29: fleet emission factors (g/km) for road transport in BAU CES and BAU VITO for the years 2000-2010-2020

			CES			**VITO**		
Vehicle category	**Fuel Type**	**Emission Type**	**2000**	**2010**	**2020**	**2000**	**2010**	**2020**
Car	CNG	CO		0,98	0,98	1,15	1,15	1,15
Car	CNG	CO2		123	116	163	163	163
Car	CNG	NOx		0,05	0,05	0,03	0,03	0,03
Car	CNG	PM		0,001	0,001	0,001	0,001	0,001
Car	CNG	VOC		0,02	0,02	0,02	0,02	0,02
Car	Diesel	CO	0,43	0,23	0,20	0,58	0,35	0,31
Car	Diesel	CO2	175	157	147	190	170	159
Car	Diesel	NOx	0,65	0,41	0,34	0,74	0,49	0,41
Car	Diesel	PM	0,07	0,02	0,01	0,09	0,03	0,02
Car	Diesel	VOC	0,07	0,03	0,03	0,08	0,04	0,04
Car	Electric	CO		0,00	0,00	0,00	0,00	0,00
Car	Electric	CO2		0,00	0,00	0,00	0,00	0,00
Car	Electric	NOx		0,00	0,00	0,00	0,00	0,00
Car	Electric	PM		0,00	0,00	0,00	0,00	0,00
Car	Electric	VOC		0,00	0,00	0,00	0,00	0,00
Car	Fuel Cell H2	CO			0,00			
Car	Fuel Cell H2	CO2			0,00			
Car	Fuel Cell H2	NOx			0,00			
Car	Fuel Cell H2	PM			0,00			
Car	Fuel Cell H2	VOC			0,00			
Car	H2 ICE	CO			0,00			
Car	H2 ICE	CO2			0,00			
Car	H2 ICE	NOx			0,13			
Car	H2 ICE	PM			0,00			
Car	H2 ICE	VOC			0,02			
Car	Hybrid CNG	CO			0,65			0,89
Car	Hybrid CNG	CO2			87			90
Car	Hybrid CNG	NOx			0,04			0,03
Car	Hybrid CNG	PM			0,001			0,001
Car	Hybrid CNG	VOC			0,01			0,02
Car	Hybrid diesel	CO			0,12			0,18
Car	Hybrid diesel	CO2			121			126
Car	Hybrid diesel	NOx			0,27			0,33
Car	Hybrid diesel	PM			0,01			0,01
Car	Hybrid diesel	VOC			0,02			0,03
Car	Hybrid H2	CO			0,00			
Car	Hybrid H2	CO2			0,00			
Car	Hybrid H2	NOx			0,09			
Car	Hybrid H2	PM			0,00			
Car	Hybrid H2	VOC			0,01			
Car	Hybrid Gasoline	CO		1,14	1,14	3,03	1,51	1,48
Car	Hybrid Gasoline	CO2		117	108	150	122	117
Car	Hybrid Gasoline	NOx		0,03	0,04	0,03	0,03	0,03
Car	Hybrid Gasoline	PM		0,001	0,001	0,000	0,001	0,001
Car	Hybrid Gasoline	VOC		0,02	0,02	0,03	0,03	0,03

			CES			VITO		
Vehicle category	**Fuel Type**	**Emission Type**	**2000**	**2010**	**2020**	**2000**	**2010**	**2020**
Car	LPG	CO	7,35	2,39	1,60	7,41	3,39	1,67
Car	LPG	CO2	163	151	140	176	165	150
Car	LPG	NOx	1,06	0,06	0,04	0,88	0,15	0,03
Car	LPG	PM	0,01	0,00	0,00	0,01	0,001	0,001
Car	LPG	VOC	0,87	0,06	0,04	1,08	0,31	0,08
Car	Gasoline	CO	8,92	3,90	2,35	10,92	6,96	3,34
Car	Gasoline	CO2	176	153	140	201	183	168
Car	Gasoline	NOx	1,00	0,13	0,08	0,96	0,36	0,09
Car	Gasoline	PM	0,01	0,001	0,001	0,02	0,001	0,001
Car	Gasoline	VOC	1,11	0,10	0,07	1,39	0,24	0,08
HD Freight	Diesel	CO	1,98	1,84	1,84	2,52	2,37	2,36
HD Freight	Diesel	CO2	505	505	505	908	965	1016
HD Freight	Diesel	NOx	4,12	2,57	1,15	9,75	6,41	3,39
HD Freight	Diesel	PM	0,24	0,11	0,04	0,40	0,19	0,08
HD Freight	Diesel	VOC	1,03	0,89	0,98	1,16	1,01	1,07
HD Persons	Diesel	CO	3,29	3,03	2,97	2,88	2,64	2,62
HD Persons	Diesel	CO2	810	791	813	787	765	785
HD Persons	Diesel	NOx	10,69	7,13	2,98	9,98	6,19	3,15
HD Persons	Diesel	PM	0,33	0,17	0,06	0,40	0,18	0,07
HD Persons	Diesel	VOC	0,98	0,83	0,90	1,32	1,13	1,17
HD Persons	Fuel Cell H2	CO			0,00			
HD Persons	Fuel Cell H2	CO2			0,00			
HD Persons	Fuel Cell H2	NOx			0,00			
HD Persons	Fuel Cell H2	PM			0,00			
HD Persons	Fuel Cell H2	VOC			0,00			
HD Persons	Hybrid diesel	CO			1,55			
HD Persons	Hybrid diesel	CO2			699			
HD Persons	Hybrid diesel	NOx			2,37			
HD Persons	Hybrid diesel	PM			0,03			
HD Persons	Hybrid diesel	VOC			0,40			
LD Freight	Diesel	CO	0,91	0,29	0,18	0,67	0,32	0,28
LD Freight	Diesel	CO2	226	195	187	260	242	239
LD Freight	Diesel	NOx	1,22	0,88	0,62	1,43	0,86	0,75
LD Freight	Diesel	PM	0,24	0,04	0,02	0,12	0,03	0,02
LD Freight	Diesel	VOC	0,18	0,07	0,05	0,12	0,06	0,05
LD Freight	LPG	CO				12,86	6,58	2,07
LD Freight	LPG	CO2				673	704	737
LD Freight	LPG	NOx				0,26	0,10	0,02
LD Freight	LPG	PM				0,01	0,00	0,00
LD Freight	LPG	VOC				0,79	0,34	0,03
LD Freight	Gasoline	CO	10,23	2,33	1,20	14,52	5,38	2,59
LD Freight	Gasoline	CO2	239	250	241	299	299	295
LD Freight	Gasoline	NOx	2,22	0,15	0,02	1,61	0,33	0,03
LD Freight	Gasoline	PM	0,03	0,00	0,00	0,02	0,005	0,001
LD Freight	Gasoline	VOC	1,30	0,11	0,03	1,27	0,28	0,04
Moto	Gasoline	CO	17,22	8,47	7,31	19,69	14,00	12,07
Moto	Gasoline	CO2	46	65	70	81	84	85
Moto	Gasoline	NOx	0,14	0,15	0,15	0,20	0,23	0,23
Moto	Gasoline	PM	0,04	0,02	0,02	0,03	0,02	0,02
Moto	Gasoline	VOC	7,24	3,37	2,47	4,18	2,81	2,32

4.5 External costs of air pollution

4.5.1 Total external costs

The sum of all marginal environmental costs calculated amounts to 4,1 billion euro in the year 2000 and decreases to 1,8 billion euro in 2020 under BAU CES. Under BAU VITO this is respectively 8,4 and 3,5 billion euro. These numbers are considerably (50 % to 300%) higher than estimates that were published earlier. This is mainly due to the use of the newest ExternE-methodology (see paragraph 2.5) and the underestimation of diesel cars in earlier assessments. Indeed, backward calculation of present results for road transport and comparison with literature (e.g. Int Panis and De Nocker, 2001 [59]; and Int Panis et al, 2004 [88]) shows deviations less than 10 %. This demonstrates that changes to the ExternE methodology are more important than changes in traffic volumes or emission factors. For the year 2010 it can be demonstrated that the scenario presented here falls within the 95 % confidence interval given by Int Panis et al. 2004.

The differences in environmental costs between BAU CES and BAU VITO could be explained by the differences in technical composition of the vehicle fleet and traffic data (see 4.4).

The sum of all marginal environmental costs calculated decrease with 56 % in 2020 compared to 2000 under BAU CES (see Figure 27). Under BAU VITO these costs decrease with 59 %. Stratified by mode, it is clear that the contribution of rail and inland shipping is below 5 %. Depending on which BAU and the year looked at, cars contribute for 39 to 63 % to the marginal environmental costs, whereas road freight transport 30 % to 45 %.

Damages caused by primary particles from road transport strongly dominate the total even though only PM2.5 from exhaust emissions were quantified in this study. Recent developments in ExternE push to also quantify impacts from brake and tire wear that are neglected here, implying that an important advantage of e.g. inland shipping was not taken into account in this study.

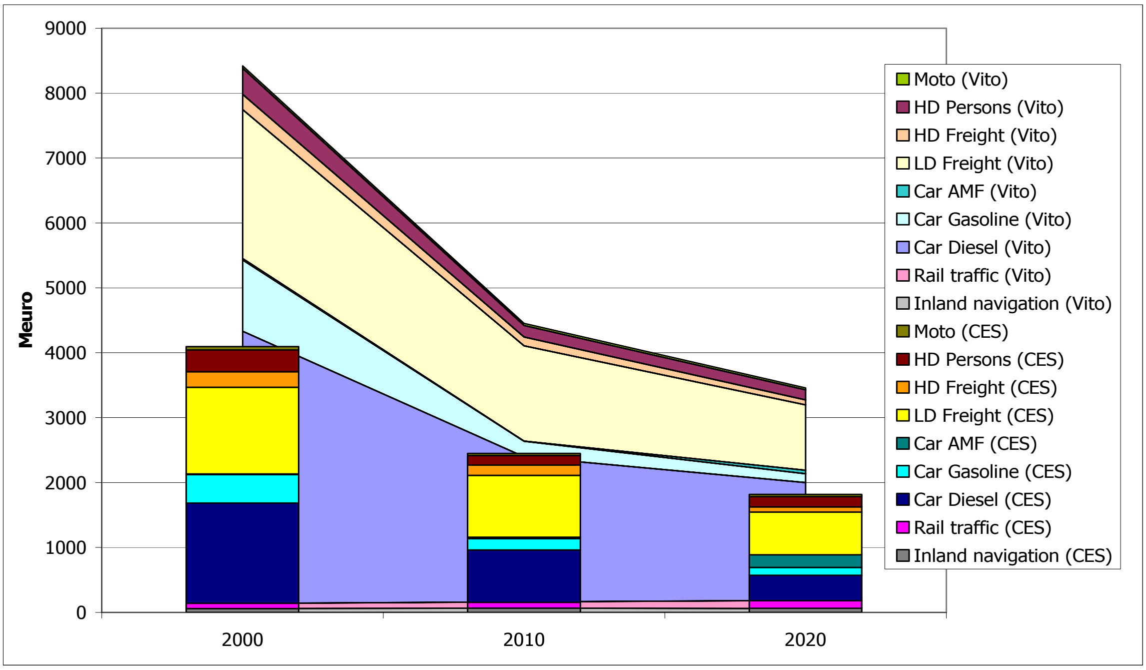

Figure 27: marginal environmental costs under BAU CES (bars) and BAU VITO (areas)

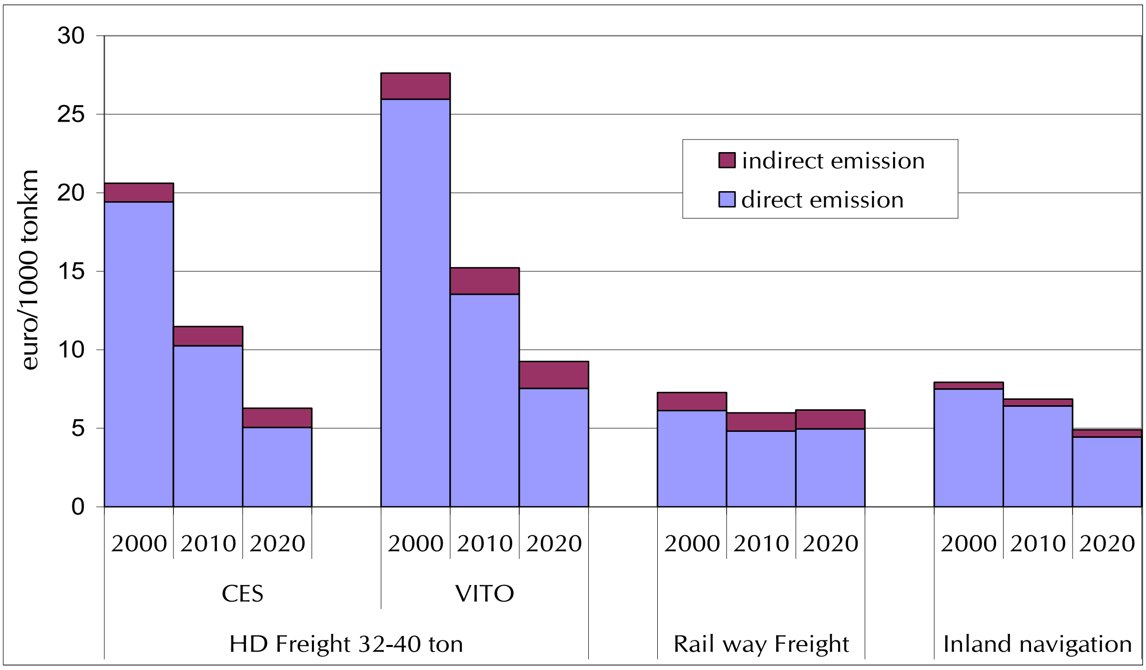

Figure 28: evolution of the marginal environmental costs for freight transport

4.5.2 Marginal cost freight transport in euro per 1000 tonkm

Figure 28 shows the evolution of the marginal environmental costs for the different transport modes used for transportation of goods. We made a distinction between indirect and direct emissions. The costs are expressed in euro per 1000 tonkm, so comparison between the different modes could easily be done.

In the period 2000-2020 the marginal environmental costs decrease for all transport modes: road transport 66 to 70 % (BAU CES versus BAU VITO), rail traffic 15 % and inland navigation by 36%. For road transport this is due to the more and more stringent emission regulations for new vehicles. For rail traffic this is mostly due to the further electrification in the period 2000-2010. For inland navigation we integrated the technological evolution within ship engines and recent emission legislations.

The marginal environmental costs are the highest for trucks, as they do not have the scale advantage (capacity per trip) trains and ships have. In the period 2000-2020 the gap between the marginal environmental costs of road transport on the one hand and train and ships on the other will become smaller. In 2000 the marginal environmental costs for a 32 to 40 tonne truck are about a factor three higher than these for trains and ships. In 2020 this will be lowered to a factor two for ships and even less for trains.

5 Policy scenarios TREMOVE (Task A, B, E)

The aim of the policy scenarios is to make an economic and environmental assessment of different policy measures. In this paragraph we will first discuss the specification of the policy scenarios that we want to simulate. In a next step we will discuss two extensions to the TREMOVE model necessary for a consistent implementation of the policy measures. Then we briefly mention the implementation path.

5.1 Specification

Based on the baseline emissions evolution, VITO identified the pollutants which have to be targeted through policy measures: PM, NO_X and CO_2. As the SUSATRANS project is about the shift towards more sustainable and cleaner technologies, the policy measures we study focus on modal shifts as well as on technological shifts in order to reduce emissions for the three identified pollutants[15].

A reduction of emissions can be obtained at the lowest social cost (excluding external effects) by levying the same tax per ton of emissions for all polluters. As we however want to reduce damage caused rather than the emissions themselves, the level of the tax has to be equal to the marginal external damage of the emissions (per mass-unit of emission; see Table 22).

The focus of a first policy scenario will be to average the taxation level of the different technologies in order to neutralise the current differences in tax levels which are not environmentally motivated (see §4.1.3.4).

In a next step we will tax different pollutants proportionally to their damage. We assume here that the marginal damage of each of the three pollutants is only a function of the emission level of that pollutant and the location of the polluter[16].

The emission tax we simulate is levied on all modes. For the road modes, the tax level is function of

- vehicle technology
- vehicle age
- region (urban or non-urban)

We should stress that we try to reduce the damage by the pollutant rather than the amount of mass emitted. In the latter case the tax would have to be equal for all regions.

With our emission tax scenario, we expect to achieve 2 objectives. First, we will achieve a given emission reduction in each type of region at the lowest cost. Second, we will push the emission reduction up to the point where the marginal cost of one ton of extra emission abatement efforts equals the marginal damage that is avoided.

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[15] Although the policy measures do not focus directly on a reduction of the overall transport activity, the TREMOVE model does take into account the evolution of the overall transport activity resulting from the policy scenario simulated.

[16] Time can also have an influence on the damage level but is not included in TREMOVE due to modelling framework limitations.

The emissions considered are tailpipe emissions only. The rationale behind this is that the remaining part of the lifecycle emissions has to be addressed by measures targeting the other activity sectors. However we added a few non-tailpipe emissions for some technologies/modes in order to allow for a more realistic emission tax simulation as discussed in the next part of this paragraph.

The tax income generated in the scenarios is explicitly assumed to be used to reduce labour taxes (see also §5.4)

5.1.1 Extension of TREMOVE

In order to allow for a consistent assessment of the emission tax simulations, we need two extensions of the TREMOVE model: an emission model and an external emission cost calculation.

The existing emission model in TREMOVE is based on an updated version of the COPERT II methodology. We decided to upgrade this to the methodology used in TREMOVE 2 which is mainly based on COPERT III [89] with only a few additions[17]. No further evolution in emission characteristics has been assumed beyond the evolution covered by COPERT (up to Euro IV for private cars and Euro V for heavy duty).

We also extended the model in order to include alternative road technologies:

- CNG: emission factors based on MEET [90];
- H_2: emission factors based on Markal database by VITO (including CO_2 emissions from steam reforming process);
- Battery: electricity-production related emissions (based on TREMOVE 2).

Hybrid technologies are assumed to have the same non fuel consumption related emissions as their conventional counterpart. The rationale behind this is that the engines of these cars will probably be tuned such as to respect the same emission standards while minimizing fuel consumption[18]. The lower fuel consumption has been taken into account in order to calculate fuel-related emissions (CO_2, SO_2).

For rail modes, emission factors have been taken from TREMOVE 2 (and from §2.4.2 for N_2O and CH_4). These emissions include both tailpipe emissions and emissions from electricity production (for electric trains and metro). The emission factors take into account a further shift towards electrical trains. The evolution of freight rail emissions is illustrated in Figure 29.

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[17] For an overview of the additions made to the COPERT III methodology we refer to the TREMOVE 2 documentation.

[18] We note that hybrid vehicles do have a potential of emission reductions e.g. when it comes to cold start emissions. The availability of hybrid car emission data for use in the TREMOVE model is however too limited to take this potential into account.

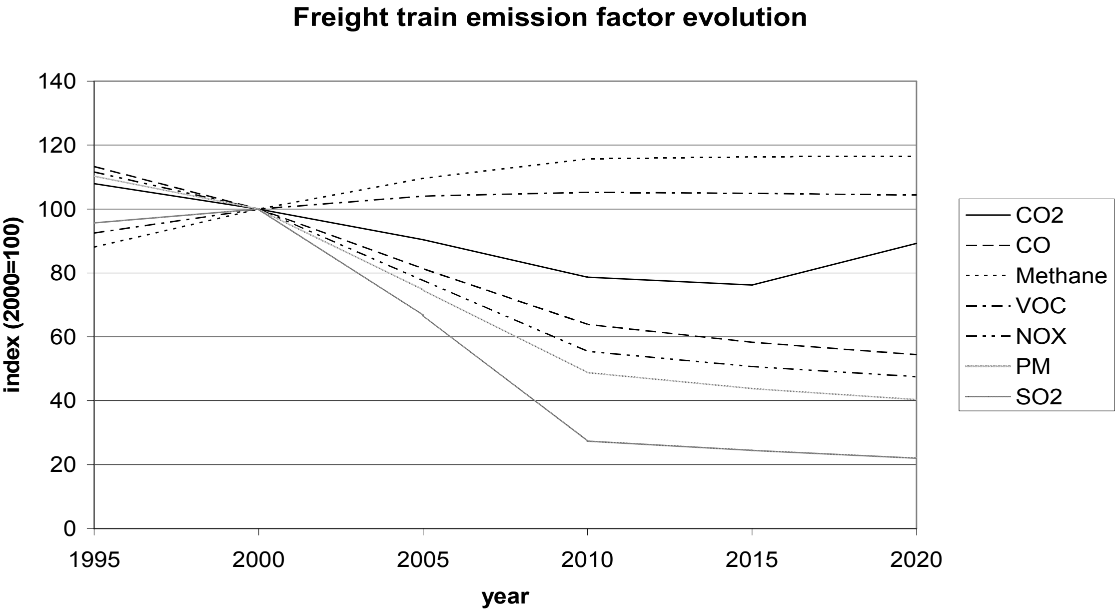

Figure 29: freight train emission factor evolution

For waterways (see Figure 30) emission factors are based on study work done by VITO (§2.4.3).

The emission model was further extended in order to allow for the calculation of both ex-post (for the modal shares) and ex-ante (for the technology choice model) emission levels.

Fuel properties (apart from prices and taxes) for road modes have been based on TREMOVE 2. A further reduction in sulphur content up to 10 ppm in 2009 is included. The reduction in emissions resulting from improved fuel standards is calculated making use of the EPEFE equations (see TREMOVE 2 documentation).

A last extension of the TREMOVE model is the incorporation of an external emission cost calculation. The external costs per (mass) unit of emission are based on VITO's update of Friedrich and Bickel (2001) (see §2.5) and are given in Table 22.

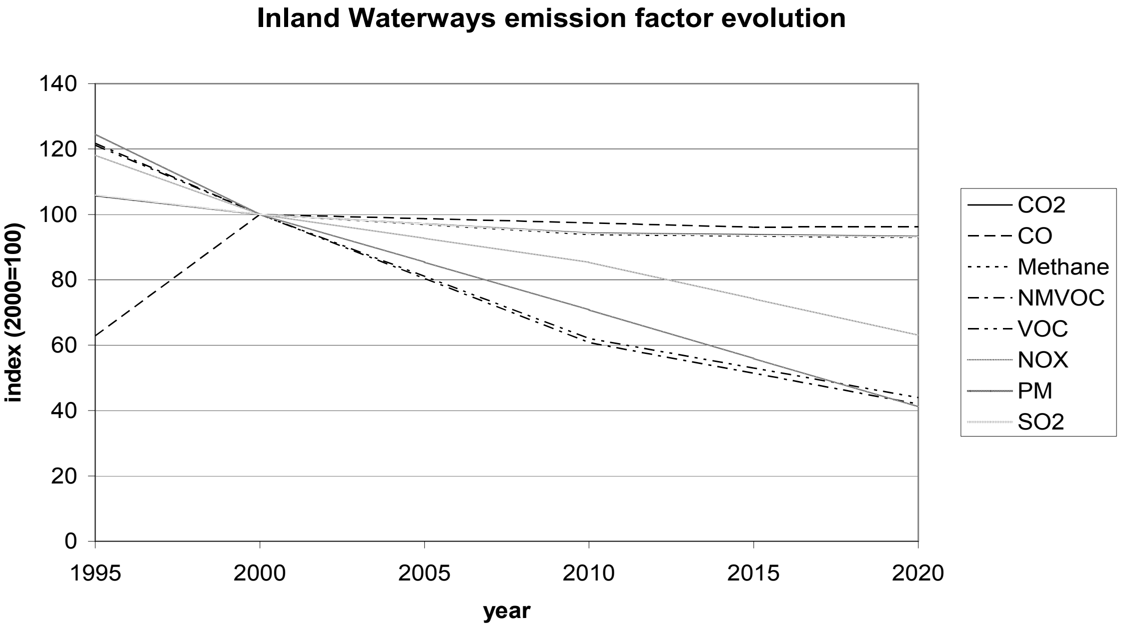

Figure 30: inland waterways emission factor evolution

5.1.2 Implementation path

We think that the re-orientation of vehicle taxes to better reflect the environmental damage that can be expected is the major element of a more sustainable transport development.
This is an obvious choice given that the use of appropriate emission taxes guarantees the achievement of environmental objectives at the lowest cost.

5.2 Levelled technology tax scenario

In §4.1.3.4 and §4.1.3.5 we studied the differences between BAU technology choice and what would be preferable from an environmental point of view. There is a difference because taxes in the BAU scenario do not reflect environmental damage[19]. This is illustrated in Figure 31.

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[19] For assumptions regarding taxes of fuels and technologies in the BAU scenario we refer to section 4.1.2.

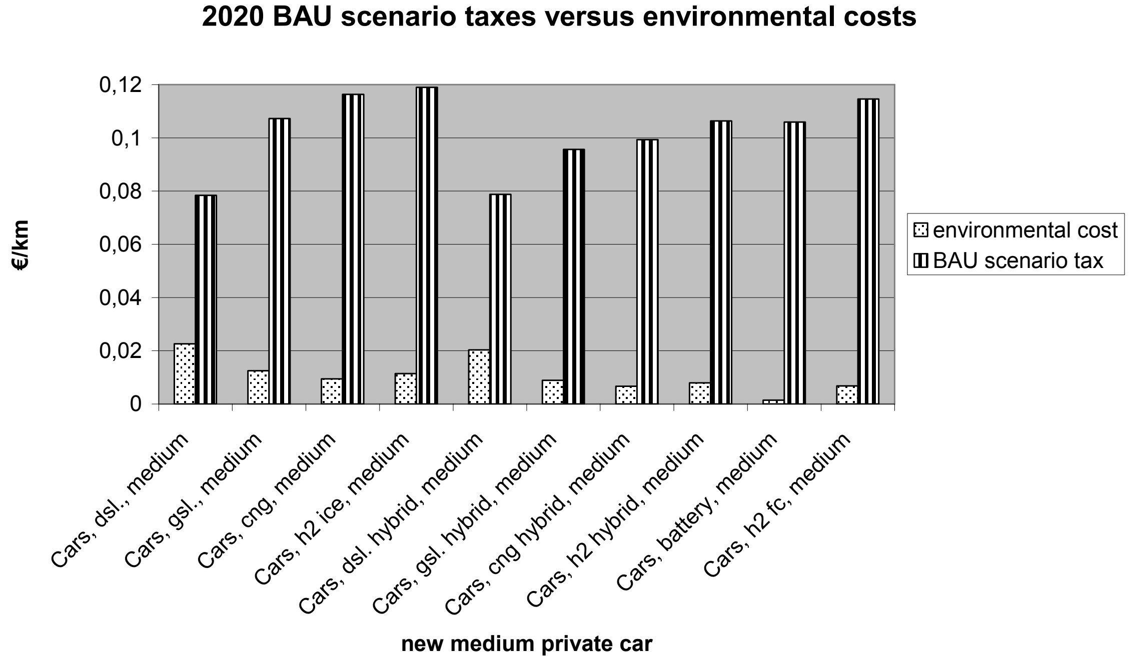

Figure 31: BAU scenario comparison of tax to environmental cost for new cars sold in 2020 (€ per vkm)

In this scenario we replace the existing taxes (from 2006 on) by a kilometre tax that amounts to the average tax level per vkm in the BAU scenario.

The technology shift in this scenario (see Figure 32) is away from less taxed technologies. Especially the share of diesel technologies becomes smaller. We also observe a shift away from hybrid vehicles towards their conventional counterparts. This is mainly explained by the high fuel taxes in the BAU scenario which magnify the fuel efficiency difference.
For LDV vehicles, we observe a rather big technology shift reflecting the higher price sensitivity assumed on this market (see §2.3.2.7).

For HDV and motorcycles, no technology shift is observed as we do not change these taxes.
As we only average the taxes over technologies of the same size category, no shift is observed between small, medium and big passenger cars.
The technology shift observed in this scenario could be considered to be sustainable in so far that we change the taxation policy such that it is environmental neutral rather than promoting whatever technology for no apparent reason (and certainly no environmental reason).

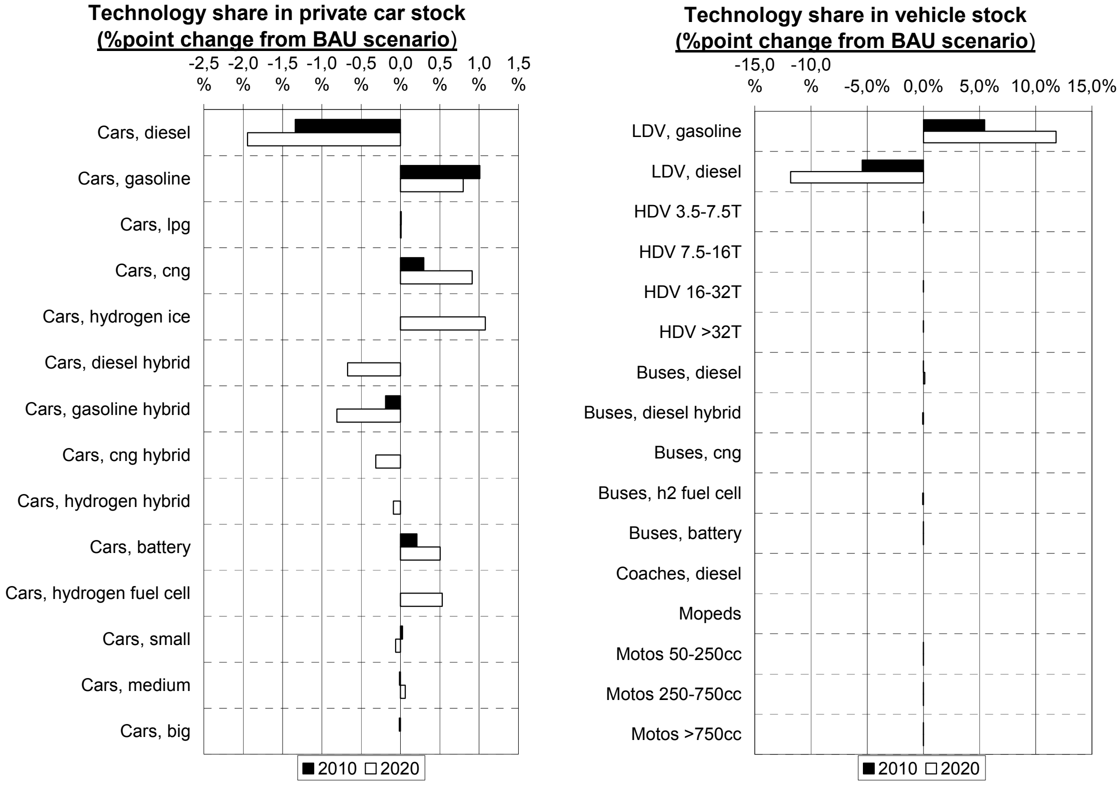

Figure 32: shift in technology stock composition at the Country level

We limit the discussion of the levelled tax scenario to the induced technology shifts as this is the only focus of this policy measure. Small modal shifts do occur in the model but they do not provide much insight.[20]

This *levelled technology tax scenario* provides a *neutral comparison* base that allows for a better understanding of subsequent environmental tax scenario that aims at a shift towards a more sustainable technology stock composition.

5.3 Emission tax scenario

An emission tax scenario has been implemented. The scenario simulates a tax on emissions of NO_X, PM and CO_2. The tax level is fixed at the external damage cost level.

The tax is levied from 2006 onwards on all technologies and modes, and the level (per mass unit) is identical for all vehicles but is differentiated over metropolitan (Brussels), other urban and non-urban[21].

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[20] Ideally, the level of the tax should be chosen such that no modal shifts or overall change in transport demand is induced. However, the TREMOVE model does not allow for this kind of optimisations and therefore the BAU-scenario tax level was used which does result in small changes in modal demand.

[21] The exercise done her is strictly limited to the question of the impact of such a tax on transport activity and does not discuss the specifications of the technical implementation of the tax. It seems to us that it should be feasible technologically, but such a system may come at a considerable cost (which is not taken into account here) and also may there be issues relating to privacy.

For PM, only diesel and electrical technologies are taxed, as there is too much uncertainty regarding the level of PM emissions for the other technologies. COPERT III does not include PM factors for gasoline cars[22].
No tax is levied on non-CO_2 greenhouse gas emissions.

The resulting emission tax covers nearly the full environmental costs (see Figure 33), although only three pollutants are taxed.

The emission tax scenario is compared to the levelled tax scenario: the emission tax is added on top of the levelled tax. This way, the only tax difference between the technologies reflects the environmental damage by the pollutants considered. Hence, a good insight in the sustainability potential of the different technologies can be obtained.

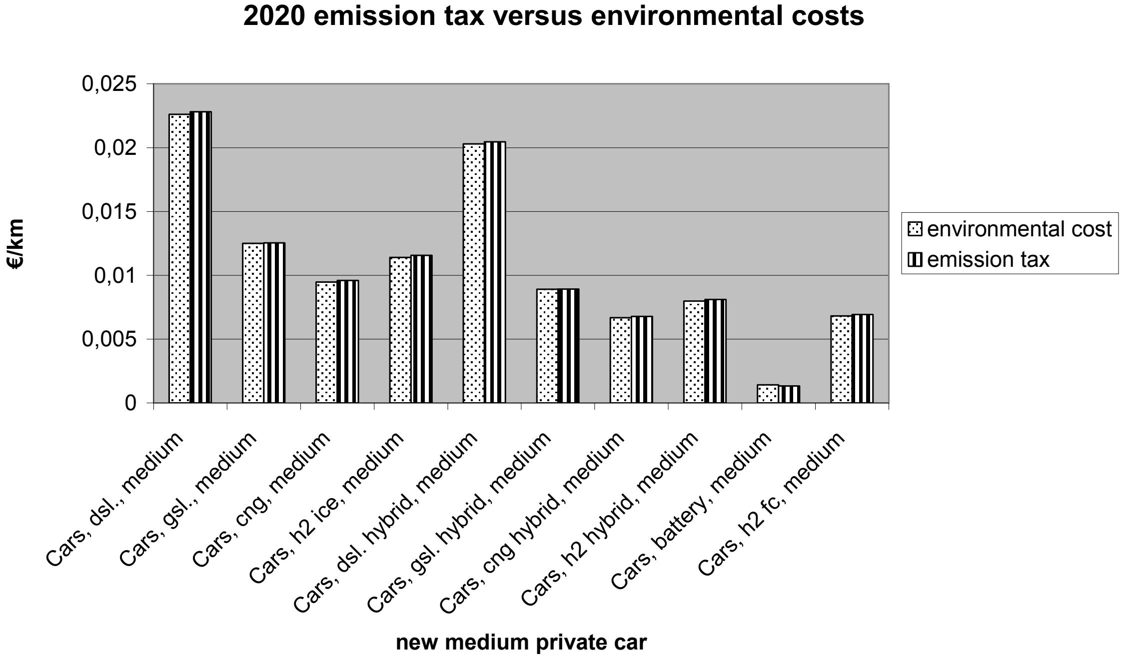

Figure 33: emission tax scenario 2020 comparison of emission tax and environmental costs (€ per vkm)

The evolution of the generalised prices is shown in Table 30. In the long term (2020) we observe the largest price increase for inland waterways; in the short term also road freight faces a considerable cost increase.

From 2005 onwards, inland navigation has a somewhat poor record when it comes to NO_X and PM emissions per tkm. This is the result of the introduction of the Euro V standard for heavy duty vehicles. Combined with a low per tkm price, the emission tax has a rather important impact[23].

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[22] In the case that we would be able to include PM emission factors for non-diesel technologies, the differences in emission tax between the technologies would be smaller and hence smaller technology shifts would result.

[23] We should remind the reader here that for non-road modes, technology shares are fixed in the BAU scenario and no further shift (e.g. towards cleaner technologies) is considered in the TREMOVE model.

For most modes we see that the price change decreases over time. This is a result of the vehicle stock becoming cleaner and hence paying fewer taxes. The activity changes are too small to result in a significant speed change apart from metro where the increased demand results in increased frequency and hence a reduction in waiting time.

Table 30: emission tax scenario change of generalised price (compared to levelled tax scenario) in €2000 per pkm or tkm

		2010	*2015*	*2020*
Urban	Small car	0,63%	0,65%	0,70%
	Large car	2,82%	2,20%	1,80%
	Bus	1,21%	0,46%	0,21%
	Metro and Train	-0,48%	-0,52%	-0,48%
	Moped & motorcycle	0,27%	0,15%	0,22%
	Non-motorised	0,02%	0,01%	0,01%
	Small truck	4,58%	3,04%	2,67%
	Big truck	7,39%	2,50%	1,17%
Non-urban	Small car	0,56%	0,58%	0,64%
	Large car	1,18%	1,08%	0,92%
	Bus	2,60%	1,77%	1,47%
	Train	1,42%	1,45%	1,81%
	Moped & motorcycle	0,71%	0,49%	0,53%
	Small truck	2,76%	2,00%	1,79%
	Big truck	5,38%	2,25%	1,31%
	Freight Train	1,40%	1,18%	1,05%
	Waterways	5,57%	5,00%	4,34%

The overall decrease in transport activity amounts to 0,9% for freight transport in 2020, for passenger transport a smaller decrease (0,5%) is observed (in 2020).

If we look to the urban area of Brussels (Figure 34), we see mainly a clear move away from large cars towards small cars, buses and metro, which is in line with generalized price evolutions. For freight transport we observe a small shift from small trucks (LDV) towards bigger vehicles (HDV) in the long term (2020).

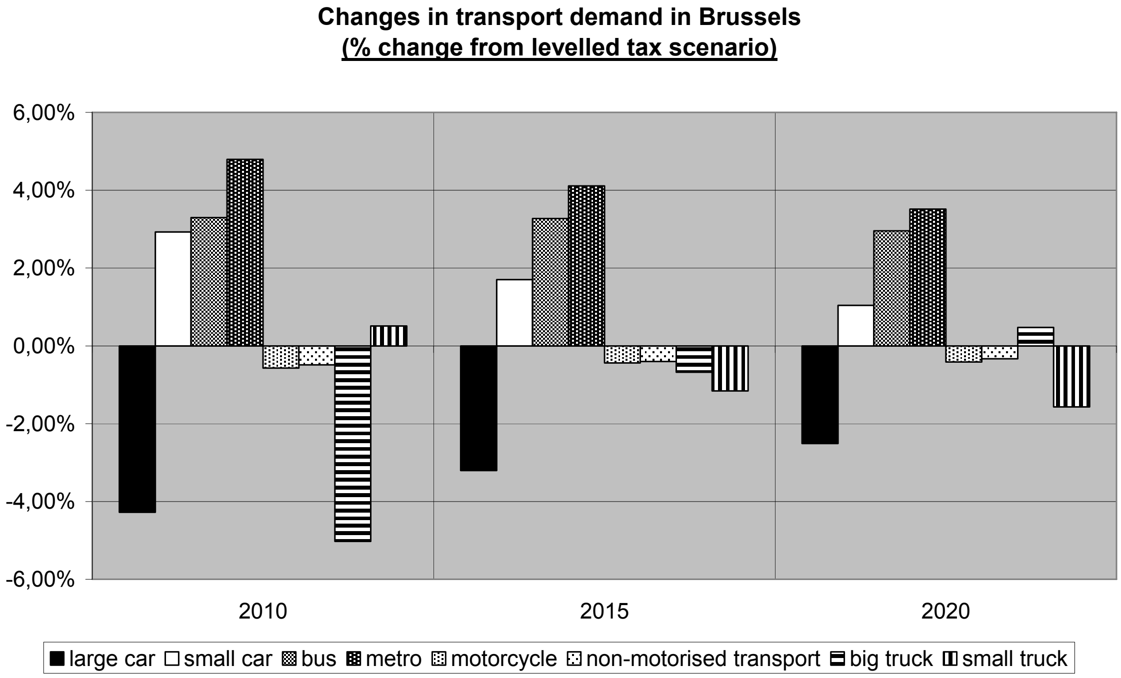

Figure 34: changes in transport demand in Brussels

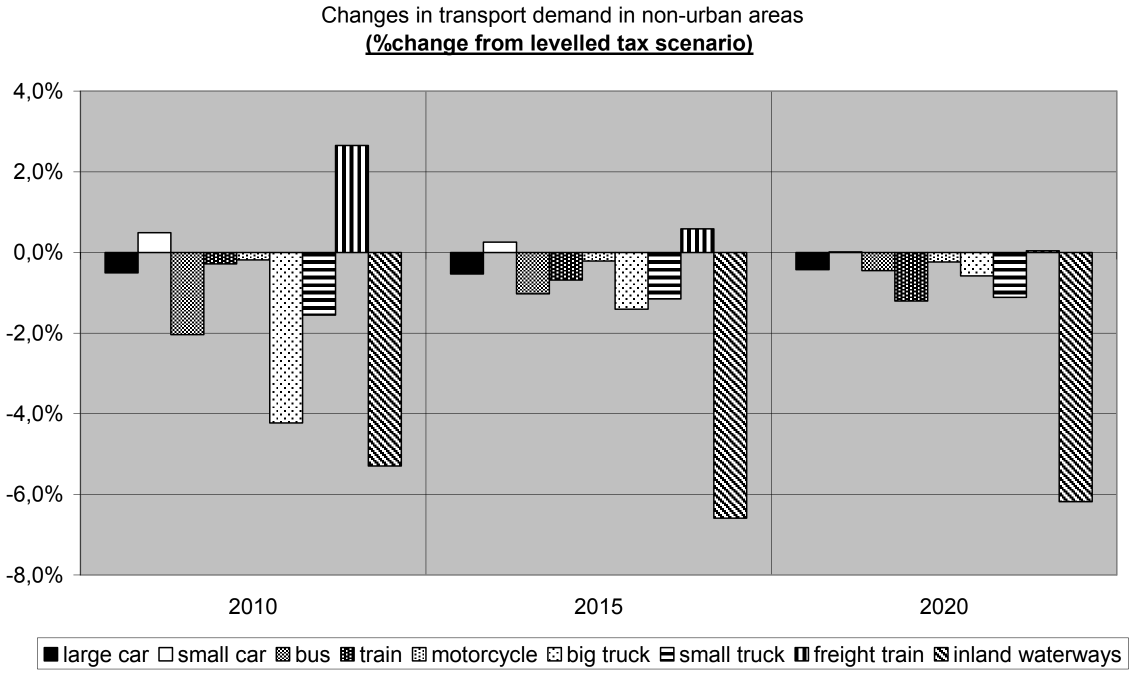

Figure 35: changes in transport demand in non-urban areas

In non-urban areas (Figure 35) the decrease in waterways activity is rather obvious (and reflecting the change in generalised price). For the other modes we observe similar shifts as for Brussels.

Freight train activity increases in the short term but this shift becomes smaller in the long term. This is the result of the evolving vehicle stocks for the road modes: on the short term, the new tax can only be anticipated by modal shift (and overall activity decrease), whereas on the longer term the stock composition changes as a function of the tax and modal shift becomes less dominant.

In the private car stock composition (Figure 36) we observe the shift from diesel to gasoline and a shift from conventional towards hybrid technologies. Gasoline vehicles produce less PM and NO_X emissions, whereas hybrid vehicles are more fuel efficient and hence emit less CO_2 compared to their conventional counterparts. Also some other technologies see an increase in their vehicle stock share.

For the light duty freight vehicles we see a shift from diesel to gasoline. This shift is bigger in percent point compared to the private car shift, as a result of the assumptions made regarding price sensitivity (see 2.3.2.7).

For buses we observe a small shift away from diesel towards mainly fuel cell buses.

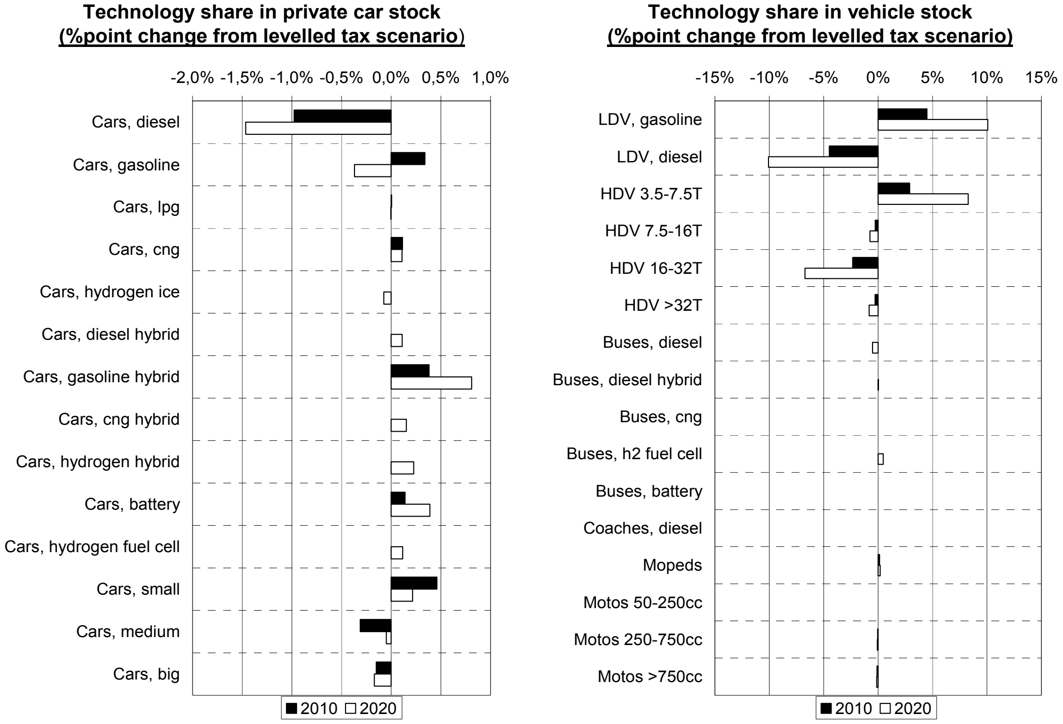

Figure 36: shift in technology stock composition at the Country level

The change in fuel consumption (Figure 37) shows a clear shift from diesel to gasoline. Also the consumption of CNG increases, due to a shift towards CNG technologies (private cars). In absolute figures, this increase is however much smaller than the increase in gasoline demand. We should remind here that CH_4 emissions are not considered in this tax scenario. In case we would tax all greenhouse gases, CH_4 technologies would probably be less successful.

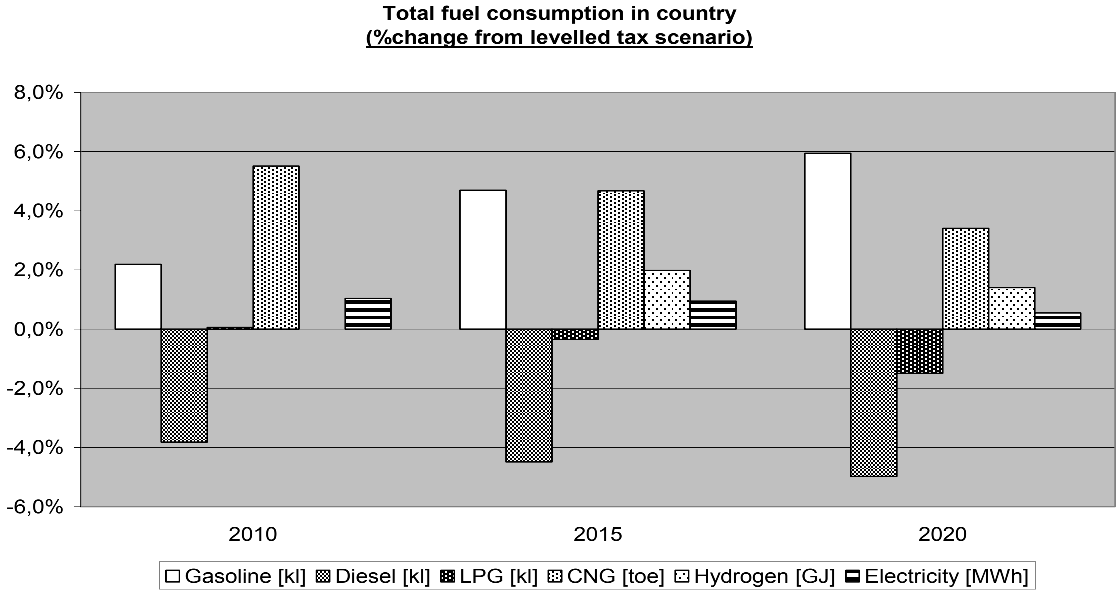

Figure 37: total fuel consumption in country

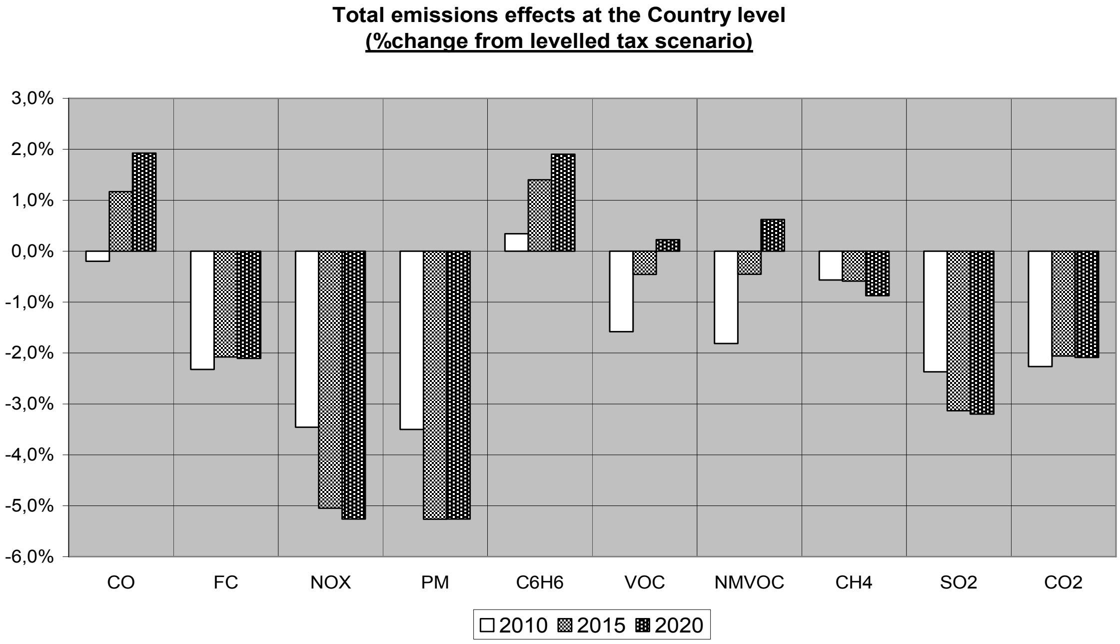

Figure 38: total emissions effects at the Country level

Looking at the emissions (Figure 38), we see a reduction of up to 5% in the targeted NO_X and PM emissions. For CO_2 the reduction is smaller (about 2%).

An important reduction for SO_2 emissions is obtained. This is a result of the reduction in inland waterways activity, where less stringent fuel standards apply compared to road modes.

5.4 Welfare assessment

We study the overall cost of the emission tax policy simulation by calculating the social cost. In a first step we look at the cost to consumers, in a next step we include the external costs and compare the scenarios.

The breakdown of the annual cost to society (Figure 39) of the emission-tax scenario shows a net gain over the whole of the modelling period. There is an increase in costs faced by both consumers and freight transport, but the increase in income for the government is nearly as big. The MCPF term (marginal cost of public funds) represents the efficiency gain of lowering labour taxes through a shift of taxes (via higher transport taxes) to non-labour income taxes[24].

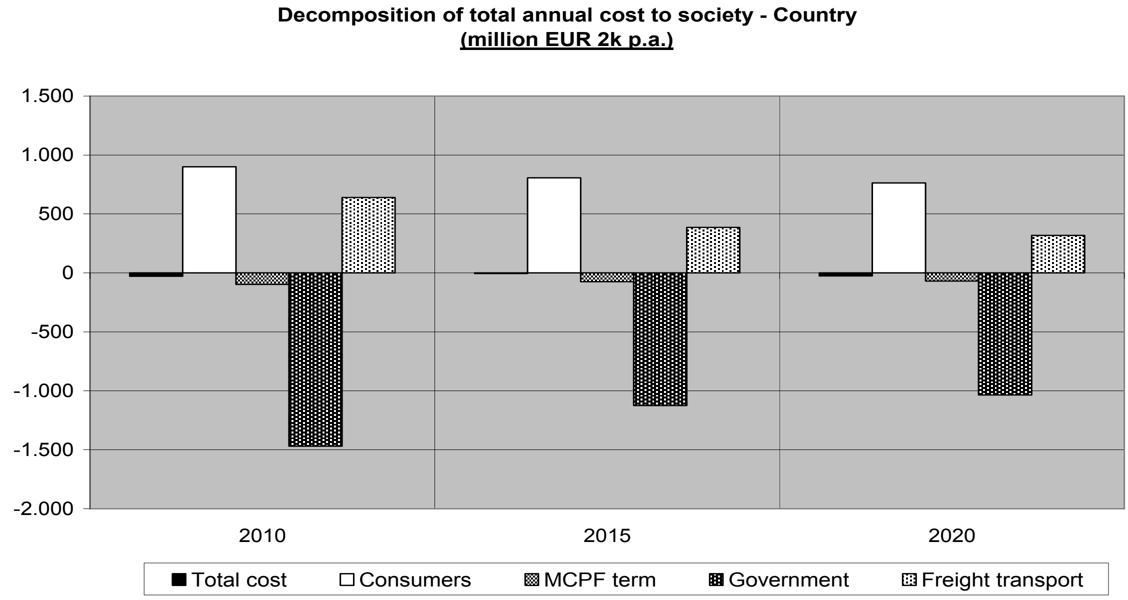

Figure 39: decomposition of total annual cost to society of emission tax scenario at the Country level (the reference is the levelled tax scenario)

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[24] We assume that there are also other sources of income that are taxed but that only taxes on labor income are reduced.

Next, we have a look to changes in external costs resulting from a change in noise, accidents and emissions. We see that for the emission tax scenario this cost is negative and hence it is a gain. Focusing on the external emission cost, we also see a gain meaning that the tax on three pollutants does not increase environmental damage from shifting to other emissions.

Table 31: annual costs of policy scenario in million €2000 (the reference is the levelled tax scenario)

	Emission tax	
	2010	2020
Social cost excl. external costs	-27,7	-24,9
Noise	-6,0	-4,1
Accidents	-68,4	-47,1
Emissions	-48,6	-50,2
Total social cost	-150,7	-126,4

Finally we calculate for the policy scenario the 2005 net present value both with and without the external costs.

Table 32: 2005 net present value of policy scenarios in million €2000 (the reference is the levelled tax scenario)

	Combined tax
Social cost excl. external costs	-261
Total social cost	-1540

The net present value of all simulations is negative, clearly showing a social gain.

6 BIOFUELS (Task C)

The sustainability evaluation performed in Task A turned out to be a more complex and more time consuming exercise than expected. Therefore, VITO decided in consultation with the user committee to limit Task C to an assessment of the feasibility of biofuels in Belgium. This reorientation is worthwhile considering the current European policy on biofuels [91, 92, 93].

In section 6 we first point out the European directives related to the introduction of biofuels in transport. Then we describe the approach used to assess the feasibility of biofuels in Belgium and the amount of land needed to fulfil the targets. We discuss the results of the stakeholder survey. Finally, we point the results from the welfare assessment of the introduction of biofuels performed by CES in an earlier study.

6.1 European directives

In its strategy towards sustainable sources for energy for climate protection and to improve the security of energy supply, the European Commission approved in 2003 two directives dealing with biofuels:

- 2003/30/EC: Directive for the promotion of the use of biofuels or other renewable fuels for transport. Targets for the member states are: 2 % market share by the end of 2005 and 5,75 % by the end of 2010. These market shares are calculated on the basis of energy content of all together gasoline and diesel for transport.

- 2003/96/EC: Directive for the taxation of energy products and electricity. Article 16 deals with biofuels and other products produced from biomass. It provides the possibility to apply an exemption or reduced rate of taxation.

6.2 Approach used for the biofuels assessment

Through a literature study and the participation to on the one hand the round table of Valbiom (Liège, 3 February 2004) and on the other hand the international CO-OPET conference on biofuels (Brussels, 26 May 2004), VITO mapped the situation of biofuels in Belgium and identified stakeholders.

The Valbiom round table concerning the perceptions and opinions of different stakeholders on biofuels was mainly focussed on the Walloon Region.

So, VITO decided to check the outcomes of the round table with stakeholders on national and Flemish level on the basis of an inquiry (see annex VI). We contacted 20 respondents in industry and agriculture organisations. The outcome is a list of perceptions of different stakeholders on biofuels. We asked for information on:
- the feasibility of the introduction of biofuels in 2006 and 2011;
- the mechanism and instruments needed to effective introduction of biofuels;

- and an estimation of the biofuels production capacity in Belgium in 2006 and 2011.

On the basis of the energy demand needed for road transport under VITO's conventional Business-As-Usual (BAU) scenario (see section 4.1.2 and annex V), the amount of land needed to fulfil the biofuel targets was also estimated.

6.3 Land needed to fulfil biofuel targets in Belgian road transport

To study the feasibility for Belgium to provide its own biomass feedstock to produce biofuels, Vito estimated the energy demand for road transport in Belgium for the period 2006-2020 under a conventional Business-As-Usual (BAU) scenario (see Table 33). This BAU-scenario takes into account the CO_2 commitments by the automobile industry for new passenger cars [94].

Table 33: energy demand for road transport in Belgium period 2006-2020 under a conventional Business-As-Usual scenario, in TJ [94]

TJ	2006	2011	2016	2020
Gasoline	65 595	49 583	41 314	36 719
Diesel	272 572	299 267	319 725	332 852

Besides the targets set by Directive 2003/30/EC we also evaluated a European strategy currently under discussion within the Alternative Motor Fuel Contact Group. Levels of up to 15% biofuels could be possible, depending on the technological progress and policy priorities [95]. To assess the amount of land needed to produce these biofuels we took into account fuel specifications and farm yields as shown in Table 34.

Table 34: fuels specification and yields for biodiesel and bio-ethanol

Fuel specification [96]					
	Unit	Diesel	Biodiesel	Gasoline	Bio ethanol
Combustion value	MJ/kg	43,27	37,70	42,72	26,8
Density	kg/l	0,85	0,88	0,755	0,79
Yield of biodiesel from rapeseed and bio ethanol from sugar beets [97]					
	ton/ha l/ha	- -	1,281 1 456	- -	4,844 6 132

In 2003 the area of land used for agriculture in Belgium was 17 511 km^2 or 1 751 100 ha [98]. We used this surface area to estimate the share of farmland needed in Belgium to provide ourselves in the amounts of biofuels set by the European targets. In the exercise it is assumed that bio-ethanol replaces x % (2 – 5,75 - 15%) of gasoline consumption and biodiesel replaces x% (2 – 5,75 - 15%) of diesel consumption, all calculated on an energy basis. Table 35 shows the result of this exercise.

About 7 to 8 % of the available farmland has to be used to fulfil the 2 % biofuels target, which seems to be feasible. More than 20 % of the Belgian farmland has to be used to provide ourselves with 5,75 % biofuels. That even goes up to 60 % for the possible future European biofuel strategy. For Belgium it is not feasible to provide itself with biofuels once the share of biofuels rises above 2 % of the total energy demand for road transport.

Table 35: share of farmland needed in Belgium to fulfil ourselves in the biofuel targets period 2006-2020, in %

Biofuel target/ future strategy	Share of farmland needed for biofuel additives, %			
	2006	2011	2016	2020
2,00 %	7,0	7,5	7,9	8,2
5,75 %	-	22	23	24
*15,00 %	-	-	59	61

*Future European strategy currently under discussion within the Alternative Motor Fuel Contact Group.

The above analysis does not take into account an increase of efficiency of the biomass conversion technologies or improved yields per hectare (e.g. by genetically modified plants). But even more efficient conversion technologies and the use of organic waste to produce biofuels will not be enough to provide ourselves with high share of biofuels. To fulfil the target of 5,75 % and higher shares of biofuels, Belgium will have to import biomass feedstock or biofuels.

6.4 Results of the stakeholder survey

Half of the respondents answered VITO's inquiry on the feasibility of biofuels in Belgium. Most stakeholders believe that the 2 % target by 2006 is achievable if supporting measures are worked out. Although most of the respondents think that it will be hard to fulfil the 2011 target and that the import of biofuels will be required.

VITO compared the amount of biodiesel (esterified rape seed oil) needed to fulfil the biofuel targets with the production potential for biodiesel in Belgium (see Table 36). This production potential was a result of the inquiry. We have to bear in mind that the production potential could in one case be rather optimistic as the capacity is not always yet there, on the other hand VITO could probably not reach all the production plants. This is especially the case for smaller plants producing pure vegetable oil. We assume that both uncertainties compensate to a certain extent.

Table 36 indicates that Belgium could not provide itself with 2 % biodiesel by 2006, this will probably be the case in 2011. Although it seems that Belgian production capacity for biofuels will be far insufficient to fulfil the 5,75 % target. It can be concluded that import of biofuels will be required.

Table 36: required esterified rape seed oil versus the estimated production capacity in Belgium

	Unit	2006	2011
Production potential esterified RSO	TJ	3 770	7 917
Required esterified RSO*			
2,00%	TJ	5 451	5 985
5,75%	TJ		17 208
Required/Production potential		1,45	0,76 2,17

* RSO = Rape seed oil

Figure 40 shows the different mechanisms and instruments which were valued by the surveyed stakeholders as either necessary, desired or needless. The exemption or reduction of tax on biofuels seems to be inevitable. Producing biofuels is a factor 2 to 4 times more expensive (before adding tax) than fossil diesel [99, 100]. Support for Belgian farmers is also very important to stimulate a Belgian biomass feedstock. Furthermore, good communication between all kind of stakeholders has to be established. Also fuel quality standards have to be guaranteed, otherwise vehicle manufacturers will not support the introduction of biofuels. There is also the need to set up research and development programmes in relation to biomass conversion technologies.

The automotive fuel market in Belgium continues to have a strong decrease in gasoline demand and an continuous increase of diesel [101]. Belgium became a diesel market country as many other European countries. As a result oil refineries in Western Europe have a surplus of gasoline and a shortage of diesel, so there is also a practical drive to focus biofuels in Western Europe on diesel replacing fuels (e.g. biodiesel, or synthetic biomass based diesel).

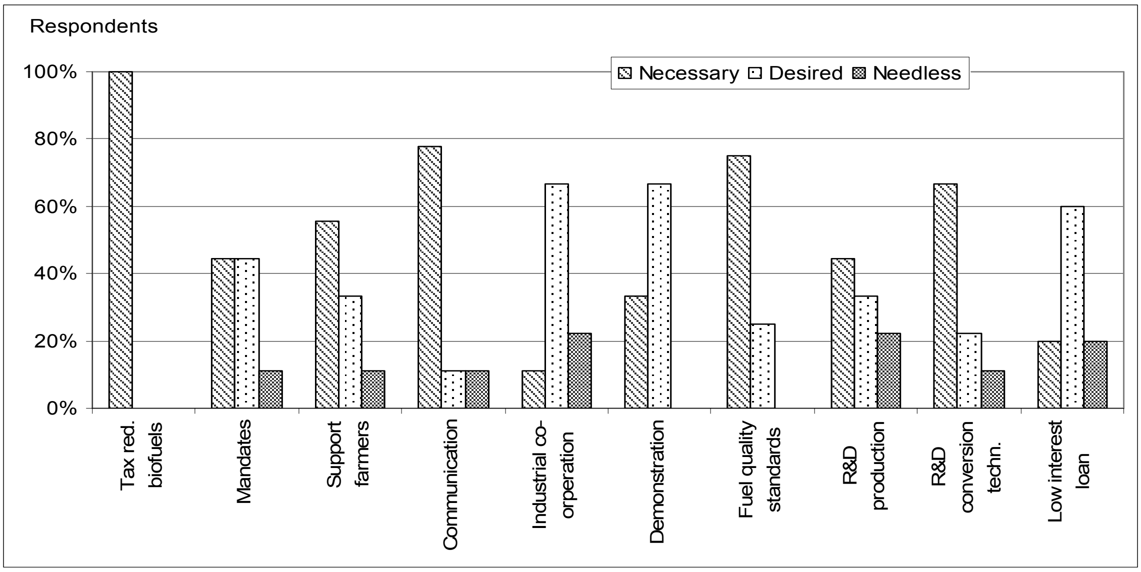

Figure 40: mechanisms and instruments needed to stimulate biofuels in Belgium

When blended with conventional fuels to a certain degree, up to 5 % for biodiesel (esterified) and up to 15 % for ETBE (Ethyl Tertiary Butyl Ether) produced from bio-ethanol, biofuels can be transported using the existing infrastructure (logistics) and no modifications are needed for nowadays vehicles [100, 102, 103]. So, optimal blending in conventional fuels is currently and at the mid term a very feasible way to introduce biofuels at a large scale.

Long-term guarantees of authorities for economic profitability for biofuels are very important for the effective introduction of biofuels. In Belgium the government is currently working out a tax reduction system for biofuels.

Currently the feasibility of biofuels for transport in Belgium is under study more in detail in the LIBIOFUELS project (Liquid Biofuels in Belgium in a global bio-energy context) [104]. The overall objective is to analyze the ecological, micro-economic and socio-economic sustainability of the most promising large scale biomass routes in Belgium. The final report will be available by the beginning of 2006. The project includes:

- a full assessment on short and medium term possibilities on biofuels for the transport sector;
- a comparison of the potential and sustainability of the chains in Belgium versus imported biomass, liquid bio-fuels or intermediate products;
- and a comparison of liquid biofuel chains with bio-CHP and bio-electricity chains.

For more information on the feasibility of renewable energy in Belgium in sectors other than transport we refer to a report recently available at the Belgian Science Policy [105].

In June 2004 the European research project PREMIA started [106] under coordination of VITO. One of the objectives of PREMIA is to investigate the cost-effectiveness of measures to support the market introduction of alternative motor fuels, with a focus on biofuels as a short term alternative. The project is closely cooperating with the European Commission on the implementation of the Biofuels Directives.

6.5 Welfare assessment

The welfare assessment of the introduction of biofuels has not been studied within SUSATRANS. There is however some evidence from past research which we will summarise here.

The introduction of biofuels is simulated by Knockaert et al. 2004 [107] using the PRIMES-Transport partial equilibrium model. It is assumed that biodiesel and ETBE are blended with mineral diesel respectively gasoline for all transport applications. The share of the biofuel is 1% in 2005 and 5% from 2010 on. The model also allows for dedicated technologies consuming a 85/15 bioethanol/gasoline mix.

The scenario also includes a reduction in excise taxes equal to the share of the biofuel in the blend (but not higher than 50% of the excise on the corresponding unblended mineral component) up to 2010.

The simulation reveals a small increase of transport costs even with the excise tax abatement until 2010. As a result non-urban transport activity decrease with 0,1% (passengers) to 0,3% (freight), in urban areas no significant changes occur. The fuel shift towards biofuels is limited to blending assumptions. On the technological level, no further penetration of biofuels occurs as dedicated ethanol cars remain too expensive even with the tax exemption.

The main impact of the scenario is on emissions and mainly on CO_2 and PM emissions. SO_2 emissions decrease on the short term when fuel standards are less stringent. Total environmental damage is reduced with 1,4% (compared to the PRIMES-transport BAU).

The loss in tax income is mainly limited to the period when the excise tax reduction applies.

The biofuels scenario has a net social cost which is positive meaning a welfare loss. The reduction of environmental damage does not compensate the loss in consumer surplus and the loss in tax income. The cost in the short term is much higher than in the long term, the difference being the loss of tax income resulting from the excise tax reduction. We note that reducing the excise tax in the initial period may represent a rather high cost as it does not contribute to a penetration of dedicated technologies. For a full discussion we refer to Knockaert et al. 2004 [107].

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Scientific progress

We set up a framework and performed a group decision support exercise for a discussion on which transport technologies are believed sustainable. Technological, social, economical and environmental criteria were used to select technologies for road vehicles that are achievable at midterm (2020-2025). We tested the effect of these technologies on emissions and impacts by using the TREMOVE and TEMAT models.

We extended the TREMOVE model into a performant model for environmental policy questions for the transport sector. The most important extension was the inclusion of a discrete choice model to represent the choice for alternative vehicle technologies. This choice model was built both on basis of survey data (stated preference) and on basis of market observations (revealed preference).

Moreover, also the TEMAT model was extended into an up-to-date model to calculate emissions from transport. It was validated for the years 1990 to 2003 for Belgium. We paid attention to the integration of alternative motor fuels and technologies to allow the assessment of future scenarios.

For inland navigation, we developed a technology model to calculate fuel consumption and emissions taking into account the technological evolution of ship engines.

Finally, the ExternE calculation tool for external environmental cost assessment was adopted. This approach was developed during the NewExt (2003) and ExternE-POL (2004) projects and also serves as a basis in the CAFE discussions (2005).

7.2 Findings of the SUSATRANS study

7.2.1 Sustainability assessment of road transport technologies by multiple criteria analysis

The sustainability assessment integrates environmental, economic and social aspects. The evaluation criteria and approach used for the multiple criteria analysis are described in paragraph 2.2. A detailed report on approach and results can be found in annex II.

A group decision support exercise resulted in the following potential sustainable fuels and technologies for passenger cars and light duty vehicles for the midterm future (2020): gasoline, diesel, LPG, CNG, hybrid gasoline-electric, hybrid diesel-electric, fuel cell on hydrogen from natural gas. Hydrogen based on a combustion engine

technology is less sustainable. This is because the production of hydrogen requires a lot of energy (and generates CO_2 emissions, especially when produced from fossil fuels like natural gas), while the hydrogen combustion engine is not significantly more efficient than conventional combustion engines, this in contrast to the fuel cell.
Hybrid CNG-electric and hybrid hydrogen (combustion engine)-electric are also less sustainable due to their higher cost.

By 2020 alternatives for buses will become more sustainable and conventional technologies will drop in the sustainability ranking. Especially the improvement in economic performance is remarkable. This can be explained by the fact that the lifespan of electric, hybrid and fuel cell buses increases steadily. The increase in lifetime of the buses goes together with a decrease in purchase cost. The combination of these two aspects makes that the economic performance of these technologies improves a lot.

7.2.2 Emissions under different business-as-usual scenarios

Important parameters in sustainability of transport are the emissions to air. Within SUSATRANS two Business-As-Usual (BAU) scenarios were defined. CES designed a BAU scenario in TREMOVE with a rather optimistic penetration of alternative motor fuels and technologies. VITO assumed a conservative BAU scenario with low penetration of alternatives. Also other parameters such as segmentation of heavy duty trucks over the different weight classes and average speeds differed in both approaches. This resulted in sometimes big differences in emission levels and external environmental costs. However, there were common trends in both BAU-scenarios. There is an increase for greenhouse gas emissions with about 13 % in the period 2000-2020. In the same period NO_x, NMVOC, SO_2 and PM emissions decrease considerably (51 to 93 %).

Checking against the Flemish CO_2 target (stabilisation in 2010 to 1990 level for the transport sector) and the national emission ceilings (EC/2001/81) current understandings show that the emissions of greenhouse gases and NO_x from transport do not meet this target. For NMVOC emissions the transport target will be easily met under the BAU scenarios. For the SO_2 emissions the international commitment could be reached if sulphur levels for sea-going vessels lie somewhat below the maximum allowed 1.5% sulphur.

7.2.3 Resource and welfare assessment of transport

For the policy assessment with TREMOVE CES worked with an environmental tax scenario. In this scenario we target the pollutants NO_X, PM and CO_2 and tax the emissions of these pollutants in the transport sector at the same tax rate per unit of damage. Such a scenario guarantees that a given damage reduction is realized at the lowest cost for society.

This resulted in the following insights:

- for passenger transport, modal shifts are in general not a cost-effective way to reduce pollution: in the long term, a shift towards more sustainable cleaner technologies and/or fuels is a less costly way to reduce emissions from a welfare point of view;

- more specifically for private cars, the major technology shifts that are sustainable are: shift from diesel to mainly gasoline and to a lesser extent from conventional to hybrid cars;
- for buses, fuel cells is one of the only new cost-effective technologies with some environmental potential;
- for light duty vehicles, a shift from diesel to gasoline may be a cost-effective measure for a sustainable transport policy.
- with current technologies, a modal shift of road freight to rail and inland waterways is not a cost-effective way to reduce emissions of freight transport activity in the long term. Freight rail does however have some potential on the short term when possibilities for technology stock change are limited for road modes. Compared to road freight and with present fuel taxes, inland waterways does not pay any of its external environmental costs. As a consequence, the introduction of environmental taxes tends to disfavour the inland waterways.

7.2.4 Environmental external costs of transport in Belgium

Depending on the defined BAU, the total environmental costs from transport in Belgium amounts to 4,1 or 8,4 billion euro in the year 2000 and decreases to 1,8 or 3,5 billion euro in 2020. These numbers are considerably higher than estimates that were published earlier. This is almost completely due to the use of the newest ExternE-methodology .

Compared to the BAU scenario, the environmental costs of the scenarios differ very little. This is also evident from a comparison of the emissions; the emission trends set by the BAU-scenario were only affected to a small degree by the different policy scenarios.

We also compared the marginal environmental costs per 1000 tonkm of different transport modes for goods (see Figure 28). In the period 2000-2020 the marginal environmental costs decrease for all transport modes: road transport about 70 %, rail traffic 15 % and inland navigation 36 %. For road transport this is due to the more and more stringent emission regulations for new vehicles. For rail traffic this is mostly due to the further electrification in the period 2000-2010. For inland navigation we integrated the technological evolution within ship engines and recent emission legislations.

The marginal environmental costs are the highest for trucks, as they do not have the scale advantage trains and ships have. In the period 2000-2020 the gap between the marginal environmental costs of road transport on the one hand and train and ships on the other will become smaller. In 2000 the marginal environmental costs for a 32 to 40 tonne truck are about a factor three higher than these for trains and ships. In 2020 this will be lowered to a factor two for ships and even less for trains.

7.2.5 Introduction of biofuels

We assessed the feasibility of the European biofuels targets transport (2003/30/EC) in Belgium. About 7 to 8 % of the available farmland has to be used to fulfil the 2 % biofuels target. More than 20 % of the Belgian farmland has to be used to provide ourselves with 5,75 % biofuels. This figure rises to 60 % for the possible future European biofuel strategy of 15 % biofuels. Accordingly for Belgium it is not feasible to be self-sufficient for biofuels once the share of biofuels rises above 2 % of the total energy demand for transport.

The results of the stakeholder survey indicated that if policy wants to stimulate the use of biofuels, the exemption or reduction of tax on biofuels seems to be inevitable as the production cost of biofuels is a factor 2 to 4 times more expensive (before adding tax) than fossil diesel. In Belgium the government has recently (May 2005) worked out a tax reduction system for biofuels. Furthermore, providing producers with long-term guarantees for economic profitability for biofuels is important for the effective introduction of biofuels.

7.3 Future work

It became clear that good transport data remain a priority area.

Updating of the different models with the newest information remains necessary to come up with well founded information to feed policy makers.

The design and estimation of the technology choice model mainly focused on private car technologies. The choice models for buses and road freight vehicles (both light and heavy duty) can be further refined using the methodology developed. Data availability for model estimation is however limited, efforts will be needed to collect the necessary observations (both for the revealed and stated preference approach).

To make a more detailed evaluation of the sustainability of a shift towards rail traffic, we have to take into account the technological evolution within diesel traction and not only the shift to more electric traction. A technology model for diesel train is needed.

Recent developments in ExternE push to also quantify impacts from brake and tire wear that are neglected here. In future studies we could extend our calculation of external environmental costs with non-exhaust emissions of particulate matter.

Abbreviations

AMF	Alternative Motor Fuels
APHEA	Air Pollution and health: a European Approach
ARGUS	Multicriteria method based on ordinal ranking scales
BAU	Business As Usual
BPF	Belgische Petroleum Federatie
C_6H_6	Benzene
CATI	Computer Assisted Telephone Interviewing
Cc	Cubic centimetre
CCR	Central Commission for Navigation on the Rhine
CES	Center for Economic Studies
CH_4	Methane
CHP	Combustion-Heat Plant
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
CO-OPET	Organisation for Promotion of Energy and Transport Technologies
COPERT	Computer programme to calculate emissions from road transport
DI	Direct Injection
DM	Decision maker
dsl	Diesel
E-R	Exposure-response
EC	European Commission
ETBE	Ethyl Tertiary Butyl Ether
EU	European union
EV	Electric vehicle
FC	Fuel Cell
g	Gram
GDP	Gross Domestic Product
GDSS	Group Decision Support System
gsl	Gasoline
H_2	Hydrogen
Ha	Hectare
HD	Heavy duty
HDF	Heavy duty freight
HDP	Heavy duty persons
HDV	Heavy duty vehicles
ICE	Internal Combustion Engine
IDI	Indirect Injection
kg	Kilogram
km	Kilometre
kWh	Kilowatt hour
l	Litre
LD	Light duty
LDV	Light duty vehicle
LFC	Lifetime Cost
LIBIOFUELS	Liquid Biofuels in Belgium in a global bio-energy context
LPG	Liquefied Petroleum Gas

MCPF	Marginal Cost of Public Funds
MEET	Methodology for calculating transport emissions and energy consumption
MJ	Mega Joule
MW	Motorway
N_2O	Dinitrogen oxide (laughing gas)
NG	Natural Gas
NH_3	Ammonia
NIS	Nationaal Instituut voor de Statistiek
NMMAPS	The National Morbidity, Mortality and Air pollution Study
NMVOC	Non methane volatile organic compounds
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
OP	Off peak
P	Peak
Pb	Lead
pkm	Passenger kilometre
PM	Particulate Matter
PREMIA	R&D, demonstration and incentive PRogrammes Effectiveness to facilitate and secure Market Introduction of Alternative motor fuels
PRTP	Pure Rate of Time Preference
RP	Revealed Preference
RSO	Rape seed oil
SO_2	Sulphur dioxide
SP	Stated Preference
TEMAT	Transport Emission Model to Analyse (non-) Technological measures
TJ	Terra Joule
tkm	Ton kilometre
UIC	Union International de Chemin de fer
USA	United States of America
Valbiom	Valorisation de la biomasse asbl
VITO	Vlaamse Instelling voor Technologisch Onderzoek
vkm	vehicle kilometre
VOC	Volatile organic compounds
VUB	Vrije Universiteit Brussel
WTP	Willingness to pay
y	year
YOLL	Year Of Life Lost

Overview annexes

Annex I	Duurzaamheidevaluatie van technologieën en modi in de transportsector in België, Eerste screening.
Annex II	SUSATRANS. Sustainability evaluation of individual technologies (Task A),.
Annex III:	The choice for alternative car technologies.
Annex IV:	Design of a car technology choice model for simulation of emission policies.
Annex V:	Emissiemodel TEMAT 2004 voor wegverkeer: validatie
Annex VI:	Duurzaamheidevaluatie van technologieën en modi in de transportsector in België, Technology Assessment van biobrandstoffen.
Annex VII:	Energiebesparende en emissiereducerende maatregelen voor spoorverkeer.
Annex VIII:	Baseline for car choice models.
Annex IX:	Aannames referentiescenario SUSATRANS (TREMOVE).

The annexes can be downloaded from:
http://www.belspo.be/ fedra/

Research actions

Sustainable production and consumption patterns SPSD 2 (CP)

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