TREMOVE

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DG ENV
Directorate C – Environment and Health

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TREMOVE 2.2 Model and Baseline Description

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Preface

This document is part of the TREMOVE contact LOT 2.

It describes the TREMOVE 2.2 model.

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1 Introduction

1.1 Purpose of the TREMOVE model

TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates for policies as there are road pricing, public transport pricing, emission standards, subsidies for cleaner cars etc. the transport demand, modal shifts, vehicle stock renewal and scrappage decisions as well as the emissions of air pollutants and the welfare level. The model covers passenger and freight transport in the EU15 plus 6 extra countries, and covers the period 1995-2030.

The baseline scenario as well as results of policy simulations will be crucial inputs for the Clean Air for Europe (CAFE) programme for air quality and the European Climate Change Programme (ECCP), as well as for other programmes.

1.2 History of the TREMOVE model

The previous version 1.3a of the TREMOVE model was developed in 1997-1998 by K.U.Leuven and DRI as an analytical underpinning for the European Auto-Oil II programme[1]. It is an integrated simulation model developed for the strategic analysis of costs and effects of a wide range of policy instruments and measures applicable to local, regional and European surface transport markets. The current version of the model includes nine EU Member States and was calibrated to 1995 data.

In 2002, an assessment[2] of TREMOVE was made, in which the specifications for a new and enhanced model were described.

During this project an enhanced and extended TREMOVE 2 model and baseline is developed. The new model covers now also explicitly rail, air and shipping and the model deals with a larger set of pollutants and covers all EU15 countries, Switzerland, Norway, Czech Republic, Hungary, Poland and Slovenia. The new model will be calibrated explicitly on other European transport and emission scenarios and will take on board the most recent emission computation methodology.

1.3 Current status of the model development

The TREMOVE 2 model development consists of 3 phases (lots).

This documentation only deals with the TREMOVE development in LOT 1.

LOT 1 covers the definition of the model specifications and the linkages with related models and projects, as well as the collection of data and the development and integration of the core modules of the new TREMOVE model. The main outputs of LOT 1 will be a newly developed and documented TREMOVE model and a preliminary baseline.

1 European Commission, Standard & Poors' DRI, K.U.Leuven. *The AOP II Cost – Effectiveness Study.* August 1999.
2 TRT Trasporti e Territorio. *Assessment and further development of the TREMOVE model.* Final report to the European Commission, February 2002.

<u>LOT 2</u> involves the completion of the model development including the development of policy scenarios. The baseline will be revised and improved, taking into account the outcomes of stakeholder consultations. Additional modules, which will enable the assessment of lifecycle effects and welfare costs of policy measures, will be developed and linked to the core modules of the TREMOVE model. Furthermore, the new TREMOVE model will be completed by implementing policy variables which will enable the simulation of the effects of technology related and other emission reduction policy measures. The completed new model will be calibrated and validated.

In the **<u>LOT 3</u>** 12 of main policy scenarios will be simulated. Scenarios will be defined in close co-operation with the Commission and translated into input data for the model by the project consortium. After running the model, the scenario results will be adequately documented and made available through the TREMOVE web-site.

In addition to the twelve main scenarios, about ten variants of each main scenario will be ran and documented. Thus, in total some 120 model runs are envisaged.

The ***present situation*** is that LOT 2 is almost finished. In January 2005, LOT 3 runs will start.

1.4 Model development consortium

The consortium consists of nine partners. All partners have been involved in or are working on EC projects, which are closely related to the further development of the TREMOVE model.

Given the presence of the consortium partners in related projects, their reputation based on previous successful modelling work and their in depth-knowledge of all fields of expertise relevant to the further TREMOVE development, the project team is particularly qualified to carry out this project.

<u>Project Leaders</u>

K.U.Leuven is one of the developers of the previuous TREMOVE model and **Transport & Mobility Leuven** is currently running the model in the context of different projects.

<u>Other Project Partners</u>

WSP (formerly know as ME&P) has a major role in the development of the SCENES transport forecasting model.

TRL is included in the consortium is also expertise in the field of emission modelling, as TRL leads the ARTEMIS project.

TRT Trasporti e Territorio has a major role in the development of the SCENES transport forecasting model.

INFRAS is included in the consortium for their expertise in the fields of vehicle stock and emission modelling, and their involvement both in the ARTEMIS and TRENDS projects.

GAMS Software will provide a web-based tool to run the model.

COWI developed a model to evaluate fiscal measures to reduce CO2 emissions from new passenger cars and was involved in the TERM project. Their expertise is used during the road vehicle stock modelling.

André de Palma (**adpC**) has give advise on discrete choice modelling and congestion issues.

1.5 Baseline introduction

During the TREMOVE project an enhanced and extended model and baseline are developed. TREMOVE covers road, rail, air and shipping and the model deals with a larger set of pollutants and covers all EU-15 countries, Switzerland, Norway, Czech Republic, Hungary, Poland and Slovenia. A transport model becomes available that can be applied for environmental and economic analysis of different policies and measures to reduce atmospheric emissions from all modes of transport in the enlarged European Union. The baseline scenario as well as results of policy simulations will be crucial inputs for the Clean Air for Europe (CAFE) programme for air quality and the European Climate Change Programme (ECCP), as well as for other programmes.

The model to which this report refers is the ***TREMOVE 2.2 model, version 3 December 2004***.

The development of the TREMOVE 2.2 baseline involved the construction of a coherent reference case for transport demand, vehicle stocks and emissions for all countries and model regions considered for every year from the base year 1995 until 2020.

It should be stressed that TREMOVE is a policy assessment model, not a transport- forecasting model. The baseline transport demands and modal split are exogenous to the model.

Therefore, baseline transport volumes will be extracted from the SCENES transport model. The base year of the SCENES model is 1995; the forecast year is 2020.

Starting from the SCENES transport demand forecasts and 1995 vehicle stock data, the sales and scrappage models in the vehicle stock turnover module will be used to produce vehicle stock projections for all modes. These projections are compared against observed vehicle stock data for the period 1995 – 2000 and adjustments are made to ensure a consistent vehicle stock baseline.

Next, the fuel consumption and emissions module will be run to forecast the emissions and energy consumption related to the baseline scenario. The vehicle stock and emissions baseline will be evaluated against the recently developed TRENDS baseline and reasons for deviations will be documented.

1.6 Simulation of policies

TREMOVE has been developed to compute the effects of various types of policy measures – taken in isolation or as packages – on the key drivers of transport emissions, mainly pricing policies and vehicle technology improvements. The main purpose of the model is to compute the effect of policy measures on emissions as well as the welfare costs of these policies.

The strength of TREMOVE is that is an integrated simulation model. The model simulates in a coherent way the changes in volume of transport, modal choice and vehicle choice (size & technology) for passenger as well as for freight transport relative to a transport and emissions baseline.

It should be stressed that TREMOVE is a simulation model, not a transport- forecasting model. The equations in the transport demand module are specifically designed to analyse changes in behaviour relative to the baseline transport projections because of policy changes.
Thus, policy simulation is done by changing one or more variables (as described in this report). The results will be presented as changes to the baseline (changes in transport volumes, prices, congestion, vehicle stocks, emissions, welfare costs etc.)

Concluding, the scope and level of detail of the TREMOVE model and baseline enables the simulation of policies on different levels. On one hand, the broad scope of the TREMOVE model makes it possible to assess integrated environmental policy packages covering the whole of Europe and all modes. On the other hand, the level of detail will be sufficient to simulate effects of country- or mode-specific measures.

At a European level, the baseline scenario as well as results of policy simulations will be crucial inputs for the Clean Air for Europe (CAFE) programme for air quality and the European Climate Change Programme (ECCP), as well as for other programmes.

Within the CAFE and ECCP programs various measures will be put forward aiming at reducing the environmental impact of transport. Such measures cover a wide range of instruments. Four main categories of policies can be identified which can be effectively simulated by TREMOVE.

Vehicle technology related policies

These policies include accelerating the introduction of vehicles with lower emissions, introducing after-treatment catalyst systems, improved aircraft technical standards, etc.

Basically two policy runs are possible: changing an existing vehicle type or the introduction of a new vehicle type. Modelling will be done in the vehicle stock & emissions module, but because of the link between the transport demand costs and the vehicle costs, such a policy run will also affect transport demand.

In both cases, the new vehicle technology needs to be modelled with its costs and emission factors. E.g. the introduction of a new emission standard for a certain vehicle in 2010 will of course be modelled by changing the emission factors for all vehicle purchased in 2010 and later. The price of the vehicle will also need a change. Lower emission standards will lead to higher vehicle prices. In order to keep consistency both need to be changed in TREMOVE. This may lead to (at first sight) unexpected results when a high price increase due to emission standards leads to a large modal shift and thus an unforeseen change in emissions.

Fuel quality related policies

These policies include assessing fuels of varying sulphur content, introducing alternative fuels, etc.

Fuel quality changes can be modelled by changing emission factors and – in parallel – fuels. Changes in fuels prices will affect both transport volumes (an thus congestion) and vehicle purchases.

Fiscal/taxation related policies

These policies include differentiated freight transport taxation or charges, vehicle tax incentive scheme for fuel-efficient cars or low-emission cars, fuel tax (CO_2 tax), marginal social cost pricing, etc.

All transport related prices and taxes in the model can be changed during a policy run. Tax structures are modelled in detail. Furthermore costs will be linked to each other for consistency reasons. E.g. the generalised prices of car transport in the demand module are linked with the car costs in the car logit model, which determines the market shares of different car types. The increase of a fuel tax will not only affect transport demand on the modes which use the fuel under consideration, but also for other modes (modal shift) through substitution processes and travel time changes (all road modes make use of the same infrastructure network). Fiscal policies thus will also affect total transport demand. Further, the purchase of new vehicles will be affected by the fuel tax.

Traffic management related policies

These policies include improved logistics for more efficient freight operations, freight city logistics, etc.

Traffic management policies are modelled in the transport demand module by changing the generalised prices of transport, mainly through the speed-flow curve.

If a change in policy is simulated, the demand module will calculate a new market equilibrium situation for each year. By changing the generalised prices at the lowest levels of the utility and cost trees, these changes will initially lead to changes in transport demands.

Maritime transport related policies

As substitution possibilities between maritime transport and other modes are very limited, it will be assumed that the baseline maritime movements will not be affected by policy measures. This implies that coverage of policy options w.r.t. maritime transport will be restricted to policies affecting ship technology and ship fuels. Examples of policies that will be covered by TREMOVE are : introduction of low sulphur fuels, taxes on sulphur emissions, taxes on fuel consumption, technology standards related to exhaust-gas aftertreatment,…

2 Model structure

2.1 The modular structure of the TREMOVE model

TREMOVE consist of 21 parallel country models, and one maritime model.

Each country model consists of three inter-linked ‘core’ modules: a transport demand module, a vehicle turnover module and an emission and fuel consumption module, to which we add a welfare cost module and a life cycle emissions module.

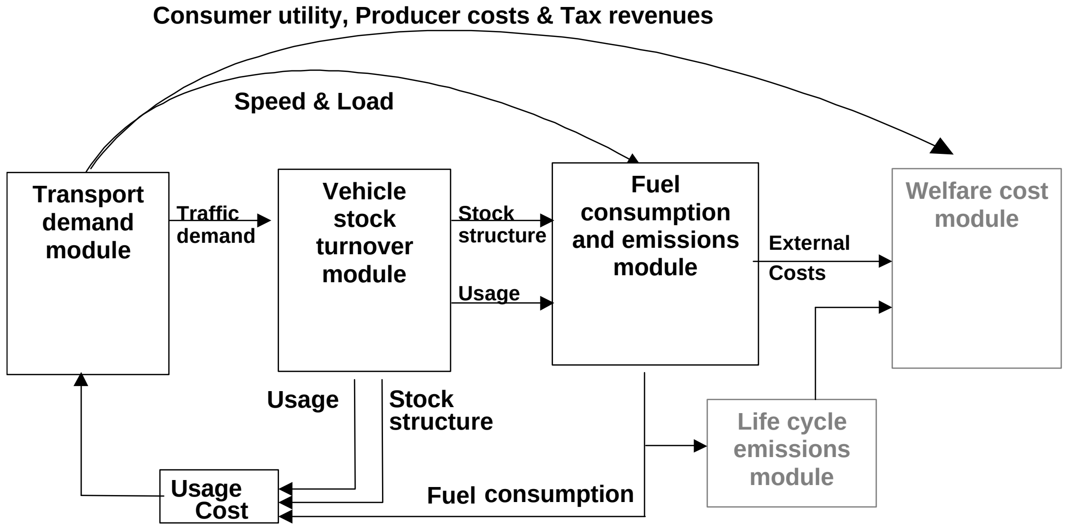


Figure 2 : Modular structure of the TREMOVE model

The *transport demand module* describes transport flows and the users’ decision making process when it comes to making their modal choice. Starting from the baseline level of demand for passenger and freight transport per mode, the module describes how the implementation of a policy measure (or a package of measures) will affect the baseline allocation of demand across different modes and different vehicle categories. The key assumption here is that the transport users will select the volume of transport and their preferred mode based on the generalised cost for each mode. The generalised cost is the sum of money costs and time costs. For non-work and commuting passenger trips, transport demand is determined by generalised prices and observed consumer preferences. For freight transport and business trips, demand level and modal choice are determined by generalised prices, desired production quantities and substitution possibilities with other production factors.

The *vehicle stock turnover module* describes how changes in demand for transport across modes or changes in price structure influence the number, the age and the type of vehicles in the stock. For this purpose both vehicle sales and vehicle scrappage decisions will be modelled for almost all modes. The sales model will enable to estimate the share of different vehicle technologies in the yearly vehicle sales under various policy scenarios. Also scrappage decisions will be explained by behavioural functions that depend, among others factors, on the policy environment. The vehicle stock module will be calibrated using historical data on the vehicle stocks in the countries considered.

The *fuel consumption and emissions module* is used to calculate fuel consumption and emissions, based on the structure of the vehicle stock, the number of kilometres driven by each vehicle type and the driving conditions.

As indicated in the previous figure, outputs from the vehicle stock and fuel consumptions and emissions modules are fed back into the demand module. As fuel consumption, stock structure and usage influence usage costs, they are important determinants of transport demand and modal split.

In the remainder of this report, the three core modules as well as related data requirements are described in more detail.

In addition to the three core modules, the TREMOVE model includes a lifecycle emissions and a welfare cost module.

The *lifecycle emissions module* enables to calculate emissions during production of fuels and electricity. Thus, the TREMOVE model does not only take into account operational vehicle emissions, but also those due to production of fuel and electricity. Since the operational emissions tend to decrease in the future, the relative share of "pre-processor" emissions will increase and may become substantial.

The *welfare cost module* has been developed to compute the cost to society associated with emission reduction scenarios in European urban and non-urban areas. The welfare effect of a policy change is calculated as the discounted sum of changes in consumer surplus, producer surplus and benefits of tax recycling. These benefits of tax recycling represent the welfare effect of avoiding public funds to be collected from other sectors, when the transport sector generates more revenues. External costs of congestion, infrastructure use, noise, accidents and pollution is as well included in the welfare cost.

2.2 The TREMOVE baseline

The development of the TREMOVE baseline involved the construction of a coherent reference case for transport demand, vehicle stocks and emissions for all countries and model regions considered for every year from the base year 1995 until 2020.

It should be stressed that TREMOVE is a policy assessment model, not a transport forecasting model. The baseline transport demands and modal split are exogenous to the model.

Therefore, baseline transport volumes have been extracted from the SCENES transport model. The base year of the SCENES model is 1995; the forecast year is 2020.

Starting from the SCENES transport demand forecasts and 1995 vehicle stock data, the sales and scrappage models in the vehicle stock turnover module will be used to produce vehicle stock projections for all modes. These projections are compared against observed vehicle stock data for the period 1995 – 2000 and adjustments are made to ensure a consistent vehicle stock baseline.

Next, the fuel consumption and emissions module has been to forecast the emissions and energy consumption related to the baseline scenario. The vehicle stock and emissions baseline will be evaluated against the recently developed TRENDS baseline and reasons for deviations will be documented.

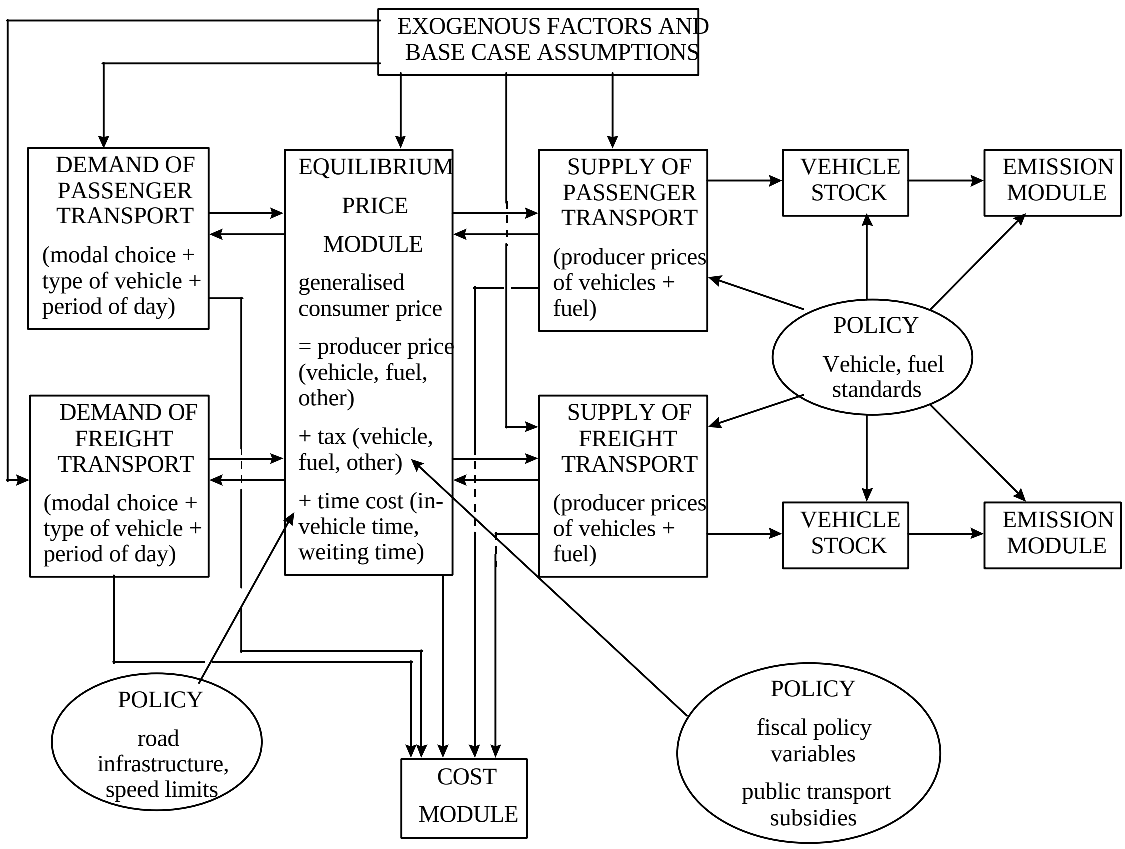
2.3 Modelling of policies

The scope and level of detail of the model and baseline enables the simulation of policies on different levels, as pricing policies, technology-related policies, alternative fuel and fuel quality policies, and transport management policies. Welfare costs of policies will be calculated taking into account costs to transport users, transport suppliers, governments as well as the general public.

On one hand, the broad scope of the TREMOVE model makes it possible to assess integrated environmental policy packages covering the whole of Europe and all modes. On the other hand, the level of detail is sufficient to simulate effects of country- or mode-specific measures.

As show in the next figure, there are 3 groups of policies that can be studies with the model. The *first group* consists of policies that affect the infrastructure. As TREMOVE has been developed for a given infrastructure, some of these policies require running the background transport network model SCENES and a reconstruction of the baseline scenario. The *second group* consists of policies that affect directly the use of different modes: road pricing, public transport pricing, etc. The *third group* of policies affects the availability, properties, costs and prices of different vehicles and fuels.

Figure 1: Modelling of policies



3 The transport demand module

3.1 Purpose of the transport demand module

The TREMOVE model consists of separate, but basically identical, country models which describe transport flows and emissions in three model regions: one metropolitan area, an aggregate of all other urban areas and an aggregate of all non-urban areas.

TREMOVE models the transport activities within these areas without explicit origin-destination disaggregation. This simplification allows us to calibrate a simple but complete policy simulation model on top of a baseline of transport flows. TREMOVE then is able first to reproduce the baseline transport flows and compute the associated emissions by mode and model region. Next it will be used for policy simulations where and the transport flows and the emissions will vary.

The transport demand module represents, for a given year, the number of passenger-kilometres (pkm) or ton-kilometres (tkm) that will be used on each mode in each model region of the country considered, and this broken down between peak and off-peak periods. With this demand module, the impact of policy measures on the transport quantity of all transport modes is calculated. A reference scenario is therefore incorporated in the TREMOVE demand module. This reference – called the baseline - is based on output of the European transport model SCENES.

3.2 Geographical structure

It should be emphasized that TREMOVE models the transport within each model region. This means that all pkm and tkm driven within the geographical boundaries of the 3 regions (metropolitan area, aggregated other urban region, non-urban region) are allocated to that model region.

This implies that for example for trips starting in the non-urban model region and ending in the metropolitan model region, the kilometres driven in the non-urban region are allocated to the non-urban region and the remaining kilometres are allocated to the metropolitan model region. The same approach holds for international traffic. In case of a journey from Amsterdam to Frankfurt, the kilometres driven in the Netherlands are included in the Netherlands figures, and the kilometres driven in Germany are included in the German data.

Using this approach one avoids that TREMOVE becomes a network model, in which explicit links between the regions need to be specified. In general, performing simulations with network models is complex and requires long computations. As the aim is to develop an integrated simulation model that is able to simulate effects of policies quickly, a network approach is avoided. Note however that the baseline traffic data will be derived from the SCENES model, which is a genuine network model.

3.3 Approach

As for all modelling exercises, the transport demand module will be a schematic representation of reality, which relies on certain assumptions of how people and firms behave "on average". The key underlying assumption in this module is that transport users will select their preferred mode based on the generalised cost for each mode.

Private transport and business transport are modelled separately in the demand module.

The Demand for private transport (non-work and commuting passenger trips) is the result of the decision processes of all households in a country. Therefore private traffic demand will be determined by generalised prices, income and observed consumer preferences.

The demand for business transport (freight transport and business trips) is modelled as a result of the decision processes within firms. The business transport demand is determined by generalised prices, desired production quantities and substitution possibilities with other production factors.

The decision processes of both firms (business demand) as households (private demand) are modelled using CES utility and cost functions. In CES[3] functions the elasticity of substitution is taken constant.

The CES utility and cost functions offer several advantages:

- They can be calibrated with a minimum of data: elasticities of substitution and observed prices and quantities.
- They are a consistent aggregate of discrete choice behaviour when the number of decision makers is sufficiently large (see Anderson et al.,1992).

A drawback of the CES functions is their constant elasticity of income and this makes them less suited for forecasting but TREMOVE has no forecasting function, this role is taken over by the SCENES model.

In the next two sections the structure of the utility and cost functions (or decision trees) for all households (private transport) and all firms (business transport) are described in detail. Subsequently the mathematical background of the CES functions is treated.

Maritime transport – both passengers (ferries) and freight – is treated in a separate section.

3.4 Private transport

The demand for commuting to work trips and non-work trips will be modelled as part of the household decision process. In TREMOVE this decision process will be represented by a nested utility function (or utility tree) for all households for each country.

At the highest level of this nested utility function there is only one utility component: total utility, which is a function of the components at the lower level. At each lower level of the utility tree, a CES utility function will be specified for each option. In CES (constant elasticity of substitution) functions,

[3] CES : Constant Elasticity of Substitution

a constant elasticity of substitution is assumed. This assumption is realistic for moderate changes in demand levels relative to the baseline (on which the nested utility function will be calibrated).

Figure 2 represents the upper part of the decision tree of all households. The lower branches of the tree are symmetric. These symmetric lower branches are also called the 'lower trees'. Two types of lower trees can be considered for the Private decision tree. The lower tree Trips Non-urban (Abbreviated as TN in the upper part of the tree) appears 8 times in the Private tree. This sub-tree describes the trip-making decisions for all non-urban transportation modes and is represented in Figure 3. The lower tree Trips Urban (Abbreviated as TU in the upper part of the tree) appears also 8 times in the Private tree. It describes the trip-making decisions for the metropolitan and other urban regions.
Figure 4 represents this lower tree.

The complete Private decision tree results in 136 different types of transport possibilities. Within the set-up of the baseline, all these lower nodes of the tree must be fed with both transport quantities and transport prices. Furthermore, a set of 137 elasticities of substitution are necessary to complete the calibration of the tree and to make it possible to calculate the impact of policy measures.

Figure 2: The decision tree for private transport – upper tree

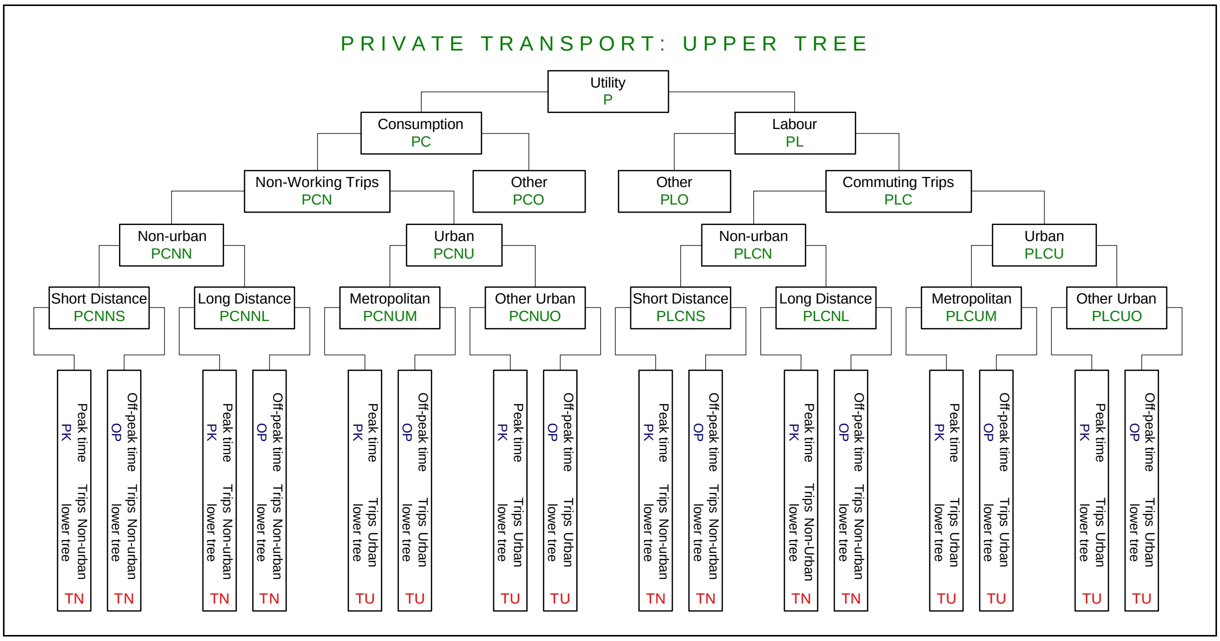


Figure 3: The decision tree for private transport – lower tree non-urban

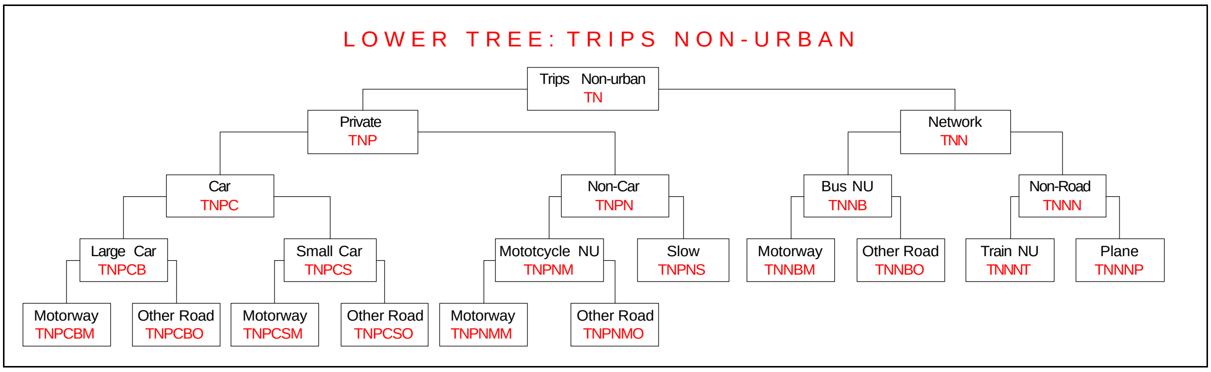
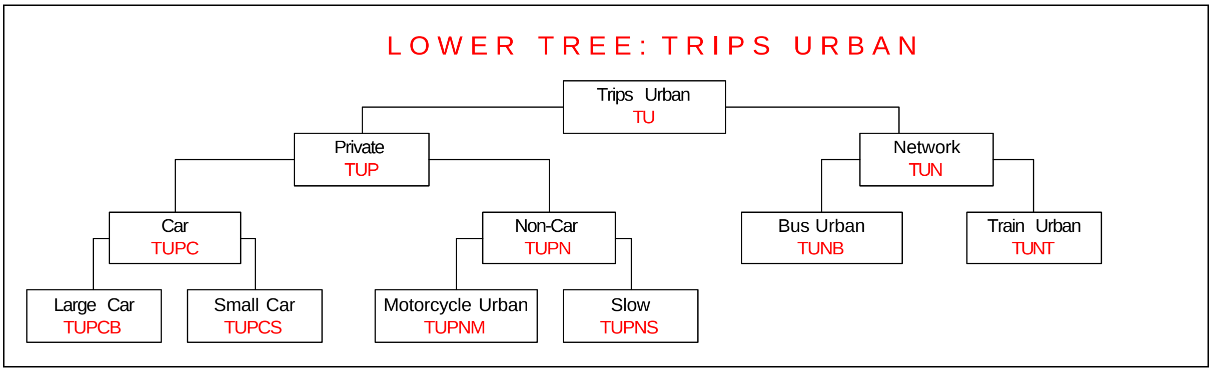


Figure 4: The decision tree for private transport – lower tree urban



Within this section the several decision levels are described in detail.

3.4.1 Choices in the labour and leisure/consumption markets

In TREMOVE, we assume that the total labour supply is fixed. Therefore, we will not model the labour market itself. The households will have to decide about the number of commuting to work trips they want for the given labour supply. The number of commuting trips can be varied by e.g. taking longer working days and telecommuting.

The number of non-work trips will result from the trade-off households make between transport and other consumption. Their preferences, income level and relative prices of transport and the prices of other consumption goods and services will determine the household decisions. As relative prices depend on the policy environment, different policy scenarios lead to different household decisions.

3.4.2 Choice of the location and time of the trip

As TREMOVE distinguishes three model regions in each country and covers urban, national and international trips, the utility tree includes levels representing the choices with respect to region and trip length.

Trips can take place in the urban areas, as well as in non-urban areas. Urban regions are split in the metropolitan case city and the collection of other urban areas. Trips in the non-urban areas are further separated in short (- 500 km) and long (+ 500 km) distance trips. By making this distinction, the modal split can be modelled more accurate. The modal split between air and rail is related to large distance trips. The modal split between rail and car is more important for short distances. The replacement of the original split up between national and international trips into short and long distances makes the models of the different countries more compatible, as the ‘international trip’ concept differs strongly between small and large countries.

The choice between travel in peak and off-peak hours is represented in the next level of the nested utility function. Note that off-peak branches are identical to peak branches.

3.4.3 Choice of modes and road types – urban

As the relevant modes and road types differ significantly between urban and non-urban areas, these levels will be discussed for urban and non-urban areas separately in the remainder of this section.

For each urban model region (= metropolitan and other urban), the same travel options will be available for non-work trips and commuting to work trips. Obviously, this does not imply that the modal shares for non-work trips and commuting trips are equal. These modal shares will be different in the baseline. By specifying different elasticities of substitution per trip motive, trip purposes can also react differently to price and speed differences. This way it is possible to, for example, model that on average consumers prefer to use non-motorised modes for non-work trips rather than for commuting trips. A review of the literature, outcomes of other projects and relevant transport models is used to determine trip purpose-specific elasticity values.

Within the decision structure of this lower urban tree the consumers have to choose first between private operated transport and network transport. Then there are choices for each mode, including large and small car, motorcycle, the slow mode, train and bus.

It should be noted that the quantities and prices for some nodes are subdivided further. The demand module divides traffic streams according to vehicle categories, while the vehicle stock splits according to vehicle types. A subdivision of some nodes improves the matching between both modules.

The transport mode “large cars” combines the vehicle categories LDV and the big/medium cars in the vehicle module. The rate of LDV passenger kilometres is taken into account explicitly in the demand module as part of the large car category.

The transport mode “urban motorcycle” combines both mopeds (e.g. scooters) and larger motorcycles. Because the rate of smaller mopeds is larger within urban regions, this was mentioned explicit in the name giving by adding the term ‘urban’.

The same considerations hold for bus and train. The transport mode “urban bus” contains both public busses and coaches. The transport mode “urban train” contains trams, metros and passenger train.

3.4.4 Choice of modes and road types – non-urban

The non-urban tree is largely the same as the urban tree. Two differences can be mentioned.

First, an additional choice level is added for road transport. A distinction is made between travelling over motorways and other roads. The main argument to include this extra level is that, amongst others, the generalised price per pkm may vary significantly between motorways and other roads. This difference exists for both monetary costs (e.g. because of pricing policies like motorway tolls) and time cost (faster travelling on motorways). A second argument is that this approach enables to simulate policies, which affect both types of traffic differently. Analysing policies that decrease motorway speed limits or assessing measures limiting heavy-duty vehicle transport on other roads, for example, will be possible.

A second addition in the non-urban tree is the choice for non-road network traffic in long distance rail and air transport.

For air transport, the number of pkm on all flights above a country is taken into account. Air transport pkm stands then for the travelled distances above the considered country for both passing flights as LTO[4] flights. In this way, the emissions of the air above a country can be calculated correctly.

Policies that affect only landing and take-off, have effects above other countries and do not involve passing flights above a country. Therefore, only policies that affect air on a EU wide scale can be incorporated in TREMOVE.

Also for the non-urban trips some nodes are subdivided. The “large car” quantities are divided again in LDV and big/medium cars. The “non-urban bus” category combines coaches and busses while “non-urban” motorcycle represents both mopeds and motorcycle. It should be noticed that the “non-urban train” category does not contain metro and tram quantities.

3.5 Business transport

Freight transport trips and business trips will be modelled as part of the decision processes of firms. In TREMOVE a nested CES cost function represents this decision process.

It is assumed that the production level of all firms in a country is given and kept constant. Within their production process, firms trade-off different logistic processes that result in different combinations of freight transport and other inputs (i.e. capital, labour). The number of freight movements and the choice of mode will be the result of cost-minimisation by firms. Similarly, business trips are considered as one of the inputs in a production process. The number of trips and the choice of mode is a result of cost minimisation by firms. The cost-minimising substitution processes will be represented by a nested CES cost function. At the highest level there is the total cost to firms, which is a function of the components at the lower levels and the total production level that is given. The nested CES cost function has a similar structure as the nested utility function for households. Both have a similar structure and the same properties, i.e. constant Elasticity’s of Substitution. Again, the latter assumption is realistic for moderate changes in demand levels relative to the baseline (on which the nested cost function will be calibrated).

Figure 5 represents the upper part of the decision tree of all firms. Four types of lower trees exist within this business decision tree. The lower trees Trips Non-urban and Trips Urban – the same lower trees as in the Private tree – both appear 4 times in the business tree. Furthermore a lower tree Freight Urban appears 4 times and also the lower tree Freight Non-urban appears 4 times in the business tree. The two types of lower freight trees are represented in Figure 8 and Figure 9.

The complete business decision tree results in 140 different types of transport possibilities (68 for passenger trips and 72 for freight transport). Therefore, the quantities and prices for all these lowest nodes must be fed with data to set up the baseline. The business tree needs 141 elasticities of substitution to complete the calibration of the tree and to model policy measures.

[4] LTO: landing and take off. These are the arriving and departing flights.

Figure 5: The business decision tree – upper tree

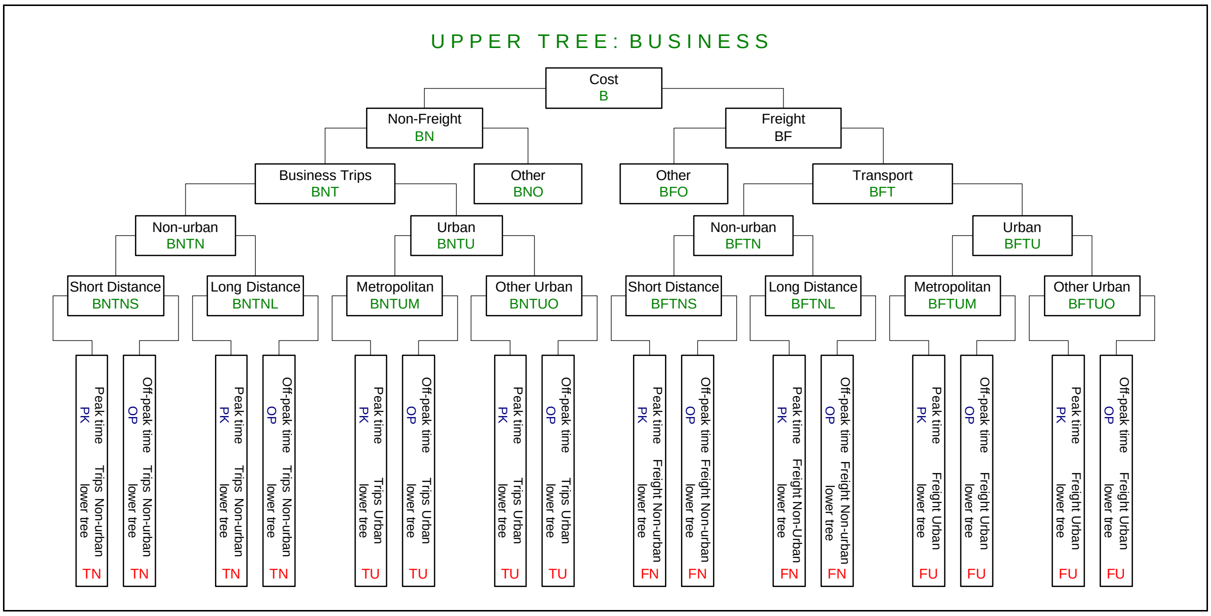


Figure 6: The business decision tree – lower tree trips non-urban

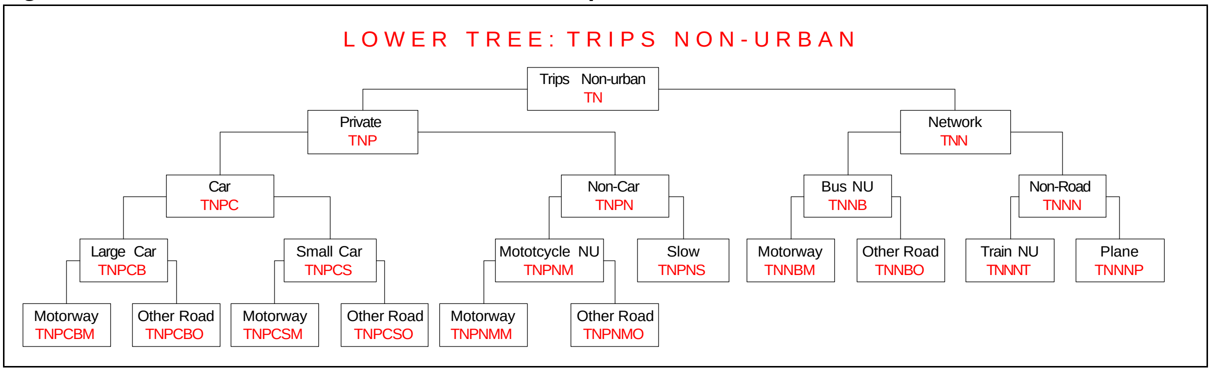


Figure 7: The business decision tree – lower tree trips urban

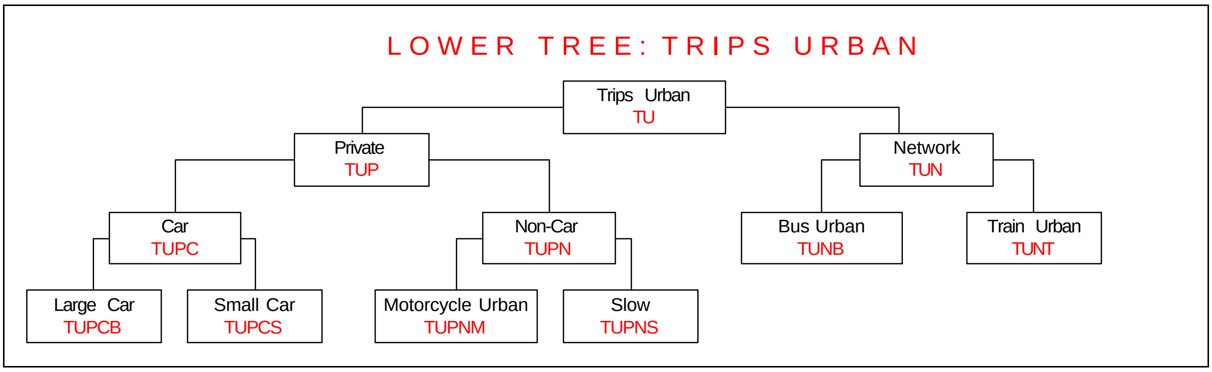


Figure 8: The business decision tree – lower tree freight non-urban

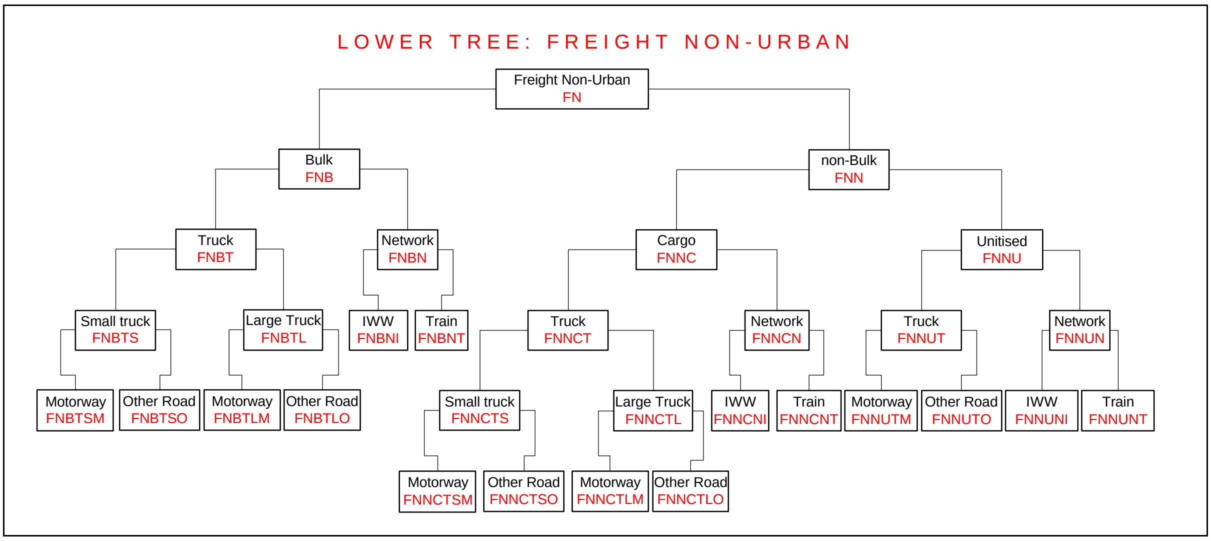
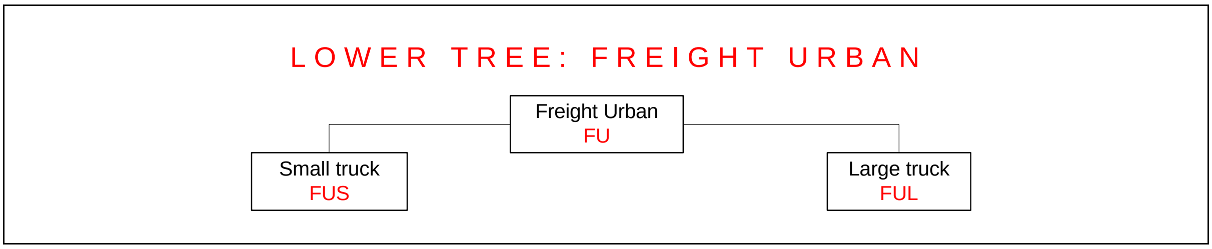


Figure 9: The business decision tree – lower tree freight urban



3.5.1 Choice between business trips, freight transport and other inputs

In principle, there is a substitution between freight transport and other inputs (larger stocks versus quicker delivery). There is also substitution between business trips and other inputs (more emailing, longer but less meetings, etc.).

The <u>trips tree</u> for business trips is exactly the same as the passenger transport tree for commuting trips or the one for non-working trips. So, basically passengers can have 3 different trip purposes: business, commuting and non-working. For every trip purpose, the transport modes are the same (but of course the prices and elasticities differ).

The <u>freight tree</u> is partly the same as the other ones: the upper levels also contain a first choice between non-urban / urban and a second choice between short / long distance and metropolitan / other urban areas.

3.5.2 Urban freight transport

For freight transport in the metropolitan area and the other urban area, the lower levels of the nested cost function are straightforward. Firms can choose between transporting goods in peak and off-peak periods and further decide whether they use small trucks or large trucks.

It should be noticed that small trucks consist of Light Duty vehicles (LDV) and other small trucks (>3.5 ton). The LDV rate is considered separately to link it correctly with the vehicle stock module. In this case LDV appear both in passenger transport (as part of the large car node for different travel motives) and freight transport (as part of the small truck node).

3.5.3 Non-urban freight transport

The choice between peak and off-peak is modelled for non-urban freight transport too. The next level in the decision tree differentiates between three types of freight transport, i.e. bulk, unitised and general cargo transport. This classification allows the use of more specific parameters to define costs, times and elasticities. Furthermore, it is obvious that not all modes are equally important for all types of freight transport.

Inter-modal transport is not treated explicitly. The share of the trip distance covered by each mode will be treated in the separate nodes in the decision tree. This is necessary to model the emissions of transport correctly. Within this structure, the effect of policy measures on a certain mode will affect the volumes of all modes in a correct way. Furthermore, the impact of typical inter-modal policies (e.g. improving transhipment from inland waterways to trucks) can be modelled by changing the elasticities of substitution between modes.
Mention that these remarks on combined freight transport are also valid for chained passenger trips.

Also for non-urban freight transport, the small truck node contains explicitly Light duty vehicles.

3.6 The CES utility mathematical specification and calibration

The demand in TREMOVE II is based on a CES (Constant Elasticity of Substitution) utility tree for representative consumers or producers. The literature is based on Keller (1976)[5].

The elasticity of substitution indicates how much one is willing to give up of one good/service in order to receive one more unit of the other good/service, while keeping the level of utility constant. Nested CES-functions are a convenient technique first because the functions can be calibrated easily, second because the structure limits the amount of behavioural parameters that are needed.

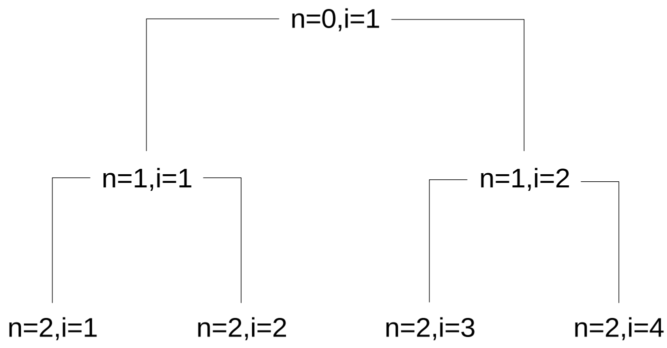
This assumption is realistic for moderate changes in demand levels relative to the baseline (on which the nested utility function will be calibrated). One of the deficiencies of a CES tree is the unitary income elasticities. This means that CES- utility functions are not appropriate for long-term forecasting.

3.6.1 Nested Utility function

The nested utility function represents demand in the form of a utility tree that consists of N+1 levels (n=0,1,2,3…N). On each level there are "*utility components*" or nodes. The top level of the tree represents overall utility, as a function of utility components at the *next lower level*. These utility components are in turn each a function of a separate group of utility components at the next lower level. At the bottom of the utility tree are so-called *elementary utility components* or *utility elements*. These are the individual commodities that are consumed. Each utility component at a next higher level represents the utility derived from the utility elements that are *associated* with this next upper level.

[5] Wouter J. Keller (1976), "A nested CES-type utility function and its demand and price-index functions", European Economic Review 7, 175-186.

Figure 10: Utility tree example



The term *association* visually means there is a vertical link between elements:

- (2,1) is associated with (1,1)
- (2,1) is associated with (0,1)
- (2,1) is *not* associated with (2,4)

3.6.2 CES-type Utility function

The CES-type utility function here will assume linear homogeneous CES relations between associated elements (j € i):

$$q_{n,i} = \left[\sum_{j \in i} a_{n+1,j}^{1/\sigma_{n,i}} \; q_{n+1,j}^{(\sigma_{n,i}-1)/\sigma_{n,i}} \right]^{\sigma_{n,i}/(\sigma_{n,i}-1)}$$

Equation 1: Consistent Quantity Index

Note that the utility components of the higher level (n) are a function of the utility components at the next lower level (n+1), using two parameters;

- a or *Keller's alpha*[6]
- σ – the elasticity of substitution.

Keller's Alpha a (n+1,j) is indexed to the lower level and sums to 1 for all adjacent nodes with the same associated node one level up.

The elasticity of substitution σ (n,i) is indexed to the upper level and is equivalent for all associated lower levels.

Both a and σ are positive numbers.

6 See: Wouter J. Keller (1976), "A nested CES-type utility function and its demand and price-index functions", European Economic Review 7, 175-186.

3.6.3 Consistent price index

By its specification, the quantity index in Equation 1 has a corresponding price index p(n,i) with identical distributional parameters;

$$p_{n,i} = \left[\sum_{j \in i} a_{n+1,j} \; p_{n+1,j}^{1-s_{n,i}} \right]^{\frac{1}{1-s_{n,i}}}$$

Equation 2: Consistent Price Index

The price index is consistent with the quantity index, meaning that the consistency of expenditures y(n,i) is maintained both vertically

$$y_{n,i} = \sum_{j \in i} y_{n+1,j}$$

Equation 3: Consistent expenditure index

and horizontally;

$$y_{n,i} = p_{n,i} q_{n,i}$$

Equation 4: Expenditure definition

Noting the prices at the commodity level, and calculating the price index of the corresponding node upwards to the top of the utility tree, can then derive the price index in Equation 2.

3.6.4 Optimal budget shares

It can be shown that optimal budget shares for the CES-type utility tree are:

$$\frac{y_{n+1,i}}{y_{n,i}} = a_{n+1,i} \left(\frac{p_{n+1,i}}{p_{n,i}} \right)^{1-s_{n,i}}$$

Equation 5: Optimal budget share

So, starting from the top of the CES utility tree, total expenditures are allocated *downwards* to utility components at the next lower level using Equation 5 .[7]

3.6.5 Elasticities

The TREMOVE model incorporates a range of elasticity values which are either exogenous or endogenous to the model.

The household utility functions and the business cost functions are nested CES functions, so assuming constant elasticity of substitution at each level of the tree. This implies that at each branching of the utility and cost trees an elasticity of substitution value must be specified. These elasticities of substitution are explicitly present in the utility and cost functions and are determined outside the model (exogenously fixed parameters). The elasticities of substitution (together with the demands and

[7] Note the difference with the construction of the price index, which is done *upward.*

prices of the "goods", i.e. the transport modes) determine the price elasticities, which are endogenous to the model. Since the price elasticities (both own and cross price elasticities) are functions of the elasticities of substitution and of demand and prices of the transport modes, they are not fixed values and so can be computed in every equilibrium situation. In TREMOVE they are computed for the base case equilibrium. Not only generalised price elasticities, but also monetary price elasticities, fuel/energy price elasticities and time cost elasticities can be computed.

To ensure that TREMOVE simulates the behaviour of households and firms correctly, accurate estimates for elasticities of substitution and price elasticities[8] were specified. Extended tests for these values are done by calculating the endogenous derived elasticities with the prices and quantities from the baseline.

3.6.5.1 *Income elasticity*

The income elasticity of any element in the CES tree ?$_{n,i}$ is 1;

$$h_{n,i} = \frac{\partial \ln q_{n,i}}{\partial \ln y_0} = 1$$

Equation 6: Income elasticity

To see this, notice in Equation 5 that optimal allocation of income is done from the top to the bottom according to relative prices, preferences a and elasticity's of substitution s – all constant parameters with respect to income. So, budget shares for each node and element are independent from the total budget itself. As a consequence 1% higher income will drive demand in the lower node up by 1 %, going down in the tree increasing all next lower demands by 1%.

3.6.5.2 *Own Price elasticity*

To derive the own price elasticity, we introduce the notation of a total budget share W(n,i) for utility components q(n,i):

$$W_{n,i} = \frac{y_{n,i}}{y_{0,i}}$$

Equation 7: Budget share notation

The own price elasticity e$_i$ for utility elements (lowest level) is:

$$e_i = \frac{\partial \ln q_{N,i}}{\partial \ln p_{N,i}} = -W_{N,i} + W_{N,i}\left[-\sum_{n=1}^{0} s_{n,i} \left(\frac{1}{W_{n+1,i}} - \frac{1}{W_{n,i}} \right) \right]$$

Equation 8: Own price elasticity

8 Elasticities of substitution are needed as they are exogenous parameters in the TREMOVE model. Estimates of price elasticities are needed to validate the model, i.e. the endogenous price elasticities in TREMOVE will be checked against price elasticities reported in scientific literature.

The first element is the **income effect**: a 1% price increase of utility element q(N,i), at given prices p(n,j) will decrease total income y($_N$) by 1% times the total budget share W(N,i). With an income elasticity ?$_{n,i}$ =1, this effect will be dispersed for all quantities demanded and effect it by –W(N,i).

The second effect is the **substitution effect** (with the Slutsky or income compensated price elasticity)[9]. Visually, the price shock translates into a change in "real" total income by the size of W(N,i) on the top of the CES-tree. This shock will transmit itself downward in quantities demanded via the optimal allocation rule in Equation 5. The part of the CES-tree where *i* is nested in, will receive a lower budget because its relative price went up (negative sign). The 'loss' goes to the other branches in the utility tree. The size of the loss will be determined by s (a higher s will lead to a higher loss to the substitutes) and by the relative expenditure shares of i at each decision node; if a higher node has a big total income share relative to the lower decision node, the "loss" is bigger.

The own price elasticity is always negative as W(n+1,i) < W(n,i).

3.6.5.3 Cross Price elasticity

The cross price elasticity $e_{i,j}$ follows a similar but distinct pattern:

$$e_{i,j} = \frac{\partial \ln q_{N,j}}{\partial \ln p_{N,i}} = -W_{N,i} + W_{N,i}\left[\frac{s_{n,i}}{W_{M,i}} - \sum_{n=M-1}^{0} s_{n,i}\left(\frac{1}{W_{n+1,i}} - \frac{1}{W_{n,i}}\right)\right]$$

Equation 9: Cross price elasticity

where M denotes the *lowest common level M* for elements q(0,i) and q(0,j)[10]. This boils down to an equivalent approach as in Equation 8 with the following distinction; the Allen elasticity of substitution (1) has an extra term (2) stops at M as lower terms are not affected by relative price changes. The extra term indicates the "loss" at M.

Notice that this "loss" is positive as the price increase in p(N,i) drives demand away from q(N,i), and hence partially towards q(N,j). Hence the sign of the cross price elasticity is undetermined ex ante unless M=0, in which case $e_{i,j}$ is strictly positive.

3.6.6 Calibration and simulation

The known input data are:

- prices and quantities of commodities (lowest level of the utility tree)
- estimates of the elasticity of substitution s (all but commodity levels)

These input data will allow the computation of:

- *Keller's alpha* a*(n,i)* , as this is not directly observable (for all but highest level of the utility tree)
- the indexes for prices p(n,i) and quantity q(n,i) for all but lowest levels.

9 All terms between brackets are referred to as the Allen elasticity of substitution.

10 The lowest level at which a component exists that is associated with both elements. To understand this visually, note that M in Figure 10 is component (1,1) for elements (2,1) and (2,2), and M is (0,1) for elements (2,1) and (2,5).

3.6.6.1 Calibration

The nested utility function for households and the nested cost functions for businesses will be calibrated against the baseline transport data. Calibrating these nested functions means assigning a value to the unknown parameters of these functions, such that the use of these functions, exactly replicates the baseline transport demand figures.

For commuting and non-work trips, the highest level of the nested utility function represents total household utility, which is a function of the components at the lower levels. As each level represents an aggregate of the nodes at the lower level, this means that total utility is a function of the consumption quantities at the lowest levels of each branch. The problem that households face is to optimise their utility given their income and the generalised prices of transport and other goods. I.e. one chooses the consumption quantities at the lowest level of each branch in order to reach a maximum welfare level, given that total expenditures must not exceed total income. This comes down to solving the following mathematical problem:

> Choose consumption quantities for transport and other goods in order to maximise total utility
> Subject to: Total expenditures = Income

As a consequence, the calibration of the nested utility function boils down to specifying the unknown parameters in the nested function such that, if baseline income and prices are in place, the consumption quantities in the solution of the mathematical problem are identical to those in the baseline. Once calibrated, the utility function is fully specified and can be used to compute demand quantities of the transport modes if income and prices are different from the baseline (i.e. if policies are introduced).

For business trips and freight transport a similar approach will be adopted. The highest level of the nested cost function represents the total cost to firms, which is a function of the input quantities at the lowest level of each branch. The problem that firms face is to choose the input quantities at the lowest level of each branch in order to minimise their total costs. As a consequence, the calibration of the nested cost function boils down to specifying the unknown parameters in the nested cost function such that, if baseline generalised prices and production levels are in place, the input quantities in the solution of the mathematical problem are identical to those in the baseline.

The calibration procedure can be summarised as:

1. calculate commodity level expenditures y(N,i) using Equation 4
2. for every *cluster* of nodes (utility elements associated with same next higher level utility element), calculate a(N,i) using Equation 5 and knowledge that for every cluster, a(N,i) sums to 1 (see simple example below)
3. calculate expenditures of the next higher level y(N-1,i) using the consistent expenditure Equation 3
4. use these results to calculate prices of the higher level p(N-1,i) using Equation 2
5. repeat steps 2 to 4 to the highest level p(0,i)
6. Derive utility index q(n,i) downward for every level using the expenditure definition in Equation 4

A simple example will explain the subroutine in step 2 ;

- Assume every cluster has 2 elements i and j.
  Derive from Equation 5 the solution for a :

$$a_{n+1,i} = \frac{y_{n+1,i}}{y_{n,i}} \left(\frac{p_{n+1,i}}{p_{n,i}} \right)^{s_{n,i}-1}$$

  and divide a (n+1,i) by a (n+1,j) to obtain a'(n+1,i,j)

$$a'_{n+1,i,j} = \frac{a_{n+1,i}}{a_{n+1,j}} = \frac{y_{n+1,i}}{y_{n+1,j}} \left(\frac{p_{n+1,i}}{p_{n+1,j}} \right)^{s_{n,i}-1} \quad \text{where s (n,i)=s (n,j)}$$

  Knowing $a_{n+1,i} + a_{n+1,j} = 1$, this becomes

$$a_{n+1,i} = \frac{a'_{n+1,i,j}}{1 + a'_{n+1,i,j}} \quad and \quad a_{n+1,j} = 1 - a_{n+1,i}$$

Equation 10: Calibration solution for a

  which can be calculated knowing expenditure and price variables of its own level

The calibration procedure has allowed for:

- calculating behavioural parameters a(n,i)
- calculating "base case" price and quantity indices for the utility tree p(n,i) and q(n,i)

3.6.6.2 Simulation

The simulation procedure requires;

- to fix behavioural parameters a(n,i) on their calibrated levels
- to specify changes in commodity prices p(N,i)
- to calculate behavioural response in quantities q(N,i)

This procedure is relatively simple as a(n,i) is already fixed:

1. Starting from commodity price changes (e.g. tax charge) at p(N,i), calculate induced price indices for higher levels working your way to the top using Equation 2.
2. Starting from the top and knowing p(n,i), calculate expenditures working your way to the bottom using the optimal budget allocation rule in Equation 5[11]
3. Use the expenditure definition in Equation 4 to derive demand and utility elements q(N,i)

3.6.7 EOS data

To ensure that TREMOVE simulates behaviour of households and companies correctly, accurate estimates for elasticities of substitution and price elasticities are specified. In this stage, a set of default values is developed, which consist of elasticity values averaged over European countries. This

[11] Assuming the total budget y_0 is known

basic set is improved to have country-specific elasticity values. Also, calculation of endogenous elasticities and comparisons with literature are made.

3.6.8 Macro-economic info

Within the upper trees, information of the transport expenditure in relation to the total budget is necessary. For the private tree, the share of transportation in total consumption expenditures and the share of transportation in total 'work related' expenditures must be known. Based on consumer indices (EC DG TREN), both transportation expenditure shares are determined as 15% of the overall budget.
The share of transportation in the total business freight expenditure is determined as 10%. The transportation share in the total freight expenditures gets the same value.

3.7 Description of the supply and equilibrium on the transport market

3.7.1 General assumptions

We model the supply of transport using cost functions. For all private modes we assume that the production of inputs (cars, tyres, gasoline etc. except for time) is characterised by constant returns to scale and perfect competition. Under these assumptions we can assume that producer prices equal marginal costs.

As already noted, the price concept, when considering the transport market equilibrium, is the generalised price. The generalised price per pkm or tkm is the sum of three elements:

- producer price
- tax or subsidy
- time cost

per km travelled by a certain mode.

The generalised price is computed for the lowest level of all branches in the nested utility function (private transport) and nested cost function (business transport). The generalised price depends on the policy environment and indirectly also on the transport quantities (e.g. in the case of congestion). So we have to compute an equilibrium volume and an equilibrium generalised price on the transport markets.

The existing SCENES model provides vehicle operating cost information and journey time information suitable for aggregation and input to the TREMOVE model.

In the next paragraphs the 3 components of the generalised price concept and the transport market equilibrium will be discussed in more detail.

3.7.2 Producer prices

The producer price for transport services consists of the producer price of all inputs necessary for these services (cars, fuels, maintenance, etc.). In principle, the producer prices are determined by the resource costs and the market structure. In TREMOVE, constant returns to scale and perfect competition are assumed. This results in producer prices, equal to marginal costs plus producer taxes.

3.7.2.1 Private passenger and freight transport costs

For most private passenger and freight transport the producer price considered in TREMOVE is the sum of the following components (all expressed in euro per passenger-/ton- kilometre)

- Vehicle purchase cost
- Maintenance cost
- Insurance cost
- Fuel cost
- Costs of parking (urban areas only)

To translate purchase costs per vehicle into costs per passenger-/ton- kilometre we used a fixed lifetime and a fixed annual mileage.

The fuel cost component is computed based on a number of variables that are calculated in other TREMOVE modules. It is a function of variables such as fuel consumption, which are dependent on technology choices, speeds (which are traffic demand-related), and truck load factors or car occupancy rates.

Not all vehicles are actually purchased by their users. In some countries, an important share of the vehicles are leased. For these vehicles, vehicle purchase costs, maintenance costs and insurance costs (as well as fuel costs, depending on the type of leasing contract) per kilometre can be aggregated in a ‘leasing cost’ per passenger- or ton- kilometre. Since not enough data was available to assess lease issues, this has not been done.

3.7.2.2 Public transport costs

For public passenger transport and rail and waterway freight transport, a linear cost function has been used. For example for passenger transport, the total cost of supplying X_p passenger-kilometre in the peak period and X_{op} passenger-kilometre in the off-peak period is given by :

$$\text{Total Cost} = FC + VC_p * X_p + VC_{op} * X_{op}$$

Where

- FC represents the fixed costs
- VC_p represents the variable operating costs (including capacity costs of carriages or buses) of transporting passengers in the peak period
- VC_{op} represents the variable operating costs (excluding capacity costs of carriages or buses) of transporting passengers in the off-peak period

3.7.3 Taxes and subsidies

On top of the resource cost the consumer usually pays taxes or receives a subsidy, both of which have been taken into account to calculate the market price.

For car, motorcycle and truck transport, the tax structure is modelled in detail. Total taxes on these modes consist of fuel taxes, purchase taxes, ownership taxes and other taxes, depending on the country.

For public transport, the tax and subsidy structure is complicated and very different between countries. The distinction between prices and costs is only important for the welfare assessment module. .

3.7.4 Transportation time costs

In TREMOVE travel times is calculated endogenously.

The time cost component in the generalised price consists of:

- Cost of in-vehicle time
- Cost of waiting time and check in/out times at terminals (for public transport only)

The cost of time is obtained by multiplying times in hours by values of time in euro per hour. Values of time vary across trip purposes, types of goods, peak/off-peak periods, regions and modes, as literature suggests that important differences exist.

Specific values of time for in-vehicle times, waiting times and walking times are specified.

3.7.4.1 Road transport: treatment of congestion

As generalised prices include the money costs and taxes as well as the transport time costs, congestion effects will influence the modal choice. If for example a policy leads to a shift from cars to public passenger transport, this will decrease congestion problems on the road and the time-component in the generalised price of car and truck transport by road will be smaller. As a consequence the policy will lead to increased truck and car transport, which will partly off-set the initial reduction of the congestion level.

The relationship between the traffic speed and the traffic flow is expressed by a congestion function. This congestion function links the different transport modes: i.e. passenger road modes and freight road modes use the same road network so that the demand for one mode determines the generalised price of the other.

Note that, as expected changes in road infrastructure may be taken into account in the baseline transport forecasts, congestion functions may vary over time. The construction and calibration of the congestion function based on SCENES data is discussed further in detail.

3.7.4.2 Public transport: the Mohring effect

The time price of urban public transport is supposed to comprise the waiting time and the in-vehicle time. Because an increase in the demand for public transport will lead to a higher frequency, the waiting time will decrease. This effect is known as the Mohring effect and is implemented in the TREMOVE model for urban busses, tram and metro. It should be noted that there is also a congestion effect (an increase in time cost with increasing transport demand) incorporated for the bus services. It is further assumed that metro and tram services do not suffer from a capacity constraint.

During the construction of the baseline, the quantities, occupancy and (operation) costs of public transport services are used from SCENES. Additional information on the average trip length and the value of time during waiting are used to calculate the frequency.

Following values are used for the average length of a trip (L_{AV}):

	bus	tram	metro
Other urban during peak period	10	15	20
Other urban during off peak	10	15	20
Metropolitan during peak period	12	18	25
Metropolitan during off-peak	12	18	25

The value of time during waiting is estimated 60% higher than the VOT while driving. This factor agrees with research done by Wardman[12].

3.7.4.3 Non-road modes

Journey times for non-road modes were derived directly from typical published timetable information and national data sources.

3.7.5 Modelling equilibrium

The baseline situation in each year represents the forecasted equilibrium situation on the market in that year, if no changes in policies are assumed. Therefore the demand module is calibrated to exactly reproduce the baseline transport quantities for each year.

If a change in policy is simulated, the demand module will calculate a new market equilibrium situation for each year. In the model input, the driving forces for transport demand, mainly the generalised price components, will be altered according to the policy. By changing the prices at the lowest levels of the utility and cost trees, these changes will initially lead to changes in transport demands. However, as these initial changes in transport demands again lead to changes in generalised prices and generalised incomes, for example through congestion effects, the new market equilibrium will have to be determined by an iterative procedure.

Therefore, in technical terms, the demand module consists of a set of linear and non-linear equations (or more correctly one set of equations for each year) which represent the mutual relationships between the demand side and the supply side of the transport market (in the year considered). Whenever a new equilibrium, i.e. policy simulation, needs to be calculated, an iterative algorithm will be applied to find a feasible solution for the sets of equations. As for the other modules of the TREMOVE model, GAMS software and algorithms will be used for this purpose.

3.8 Baseline data

The TREMOVE model consists of separate, basically identical country models which describe transport flows and emissions in three model regions: one metropolitan area, an aggregate of all other urban areas and an aggregate of all non-urban areas.

[12] Wardman M (1998) A review of British evidence on the valuation of time and service quality. Working paper 525, Institute for Transport studies, University of Leeds.

The transport demand module represents, for a given year, the number of passenger-kilometres (pkm) or ton-kilometres (tkm) that will be used on each mode in each model region of the country considered, and this broken down between peak and off-peak periods. With this demand module, the impact of policy measures on the transport quantity of all transport modes is calculated. A reference scenario is therefore incorporated in the TREMOVE demand module. This reference – called the baseline - is based on output of the European transport model SCENES.

This means that all transport quantities and prices of all the lower nodes in the demand tree are based on the output of the SCENES network model. This detailed description of the baseline together with some additional calibration information is necessary to set up the demand module. The following paragraphs clarify the SCENES model and how the output of SCENES is used for the construction of the TREMOVE Baseline.

3.9 The SCENES model

3.9.1 Overview

The SCENES transport model is an integrated passenger and freight transport model for Europe that has been developed initially for DG TREN of the European Commission[13]. It was itself a development of a model originated during a preceding European Commission research project, STREAMS.

The SCENES model is a European multi-modal passenger and freight model operating at the NUTS 2 zoning level over the twenty-three EU countries excluding Malta and Cyprus. SCENES uses a detailed European network for assignment to highways, rail, inland waterways, ferries and coastal shipping. The freight model is based on a sophisticated regional economic model (REM) using input-output techniques. The passenger model uses a more standard trip generation mechanism. The base year is 1995, and the model is designed for forecasting the effect of a range of different scenarios and policies as far as 2020.

The SCENES model has been used within a number of other recent European Commission projects including ASTRA, MC-ICAM, TIPMAC, IASON, EXPEDITE, SPECTRUM and the pilot Strategic Environmental Assessment of the Trans-European Transport Networks (TEN-Ts).

3.9.2 Model structure

The modelling structure developed is a comprehensive ‘framework’ for modelling at the European scale, in that all significant aspects of the transport market are accounted for in one shape or form within the model. It is built up using inputs from the detailed zonal level. Many parameters and data inputs within the model are also specified at the country level. The amount of detailed input required would ideally be met by a harmonised European data set, collated with this application in mind. Of course, this level of data is not currently available. Hence many of the model inputs are estimated from the best data available at the time. Therefore the model can be regarded as an initial (but comprehensive) framework, which could be updated and improved over time as more data becomes

[13] SCENES European Transport Forecasting model and Appended Module: Technical Description. SCENES Deliverable 4 to the European Commission, April 2000, See: http://www.iww.uni-karlsruhe.de/scenes/#deliverables.

available. Some of this sort of improvement was carried out within the TREMOVE project using data provided by the member states.

The structure of the SCENES model is in essence that of a traditional four-stage model, with distinct Generation – Distribution – Modal Split – Assignment components. The first two stages are within the freight and passenger demand model, while the latter two stages are in the transport supply model. However, the costs and times of travel which are output from the transport model feed into the demand model in the form of 'disutilities' (derived from zone-pair travel costs and times)– thus the system encompasses a full feedback between the two models. In this way, changes in the transport model, be it through transport cost or infrastructure changes, have a bearing on the demand for travel.

The model is designed to produce in the first instance European level transport forecasts. Comprising as it does of a wide range of demographic, economic, socio-economic and transport factors, and being built as a 'bottom up' model from the zonal level, a much greater level of spatial detail is however possible. This level of detail can be achieved because the model comprises <u>all</u> transport and travel, including very short distance trips and non-mechanised modes.

The 15 European Union countries and eight Central and Eastern Europe Countries (CEEC) comprise the 'internal' modelled area. That is, all travel within this area is modelled. The rest of the world is treated as 'external', i.e., passenger travel and freight traffic to and from these external zones is modelled. The internal modelled area is represented by 244 zones based mainly on the NUTS2 definitions, and the external area is represented by 17 'European' zones with 4 zones representing the rest of the World. The exception is that freight traffic within the CEEC area is not modelled – only freight traffic between the CEEC and the EU, i.e., only the EU15 countries are treated as internal for the freight model.

The ***passenger demand*** model combines highly segmented, zonal level socio-economic and behavioural data to produce a matrix of travel. There are 20 population groups specified in each zone and 10 trip purpose categories. The ***freight demand*** model is based on a spatial adaptation of a financial input-output structure, in order to represent linkages between industries. These inter-linkages are estimated from zonal final demand. Some 24 economic sectors are used in producing a matrix based on value, which is converted to volumes in an interface module. This freight volume matrix is combined with the passenger travel matrix and assigned to the modal networks in the common transport module.

The ***transport model*** contains a representation of the costs and times of travel by all the different modes between all of the model zones, for passenger and freight traffic. This is achieved using comprehensive and detailed multi-modal transport networks for road, rail, air, shipping, inland waterway and pipeline. An innovative treatment of intra-zonal travel for both passengers and freight allows the characteristics of even the shortest trips to be represented. The passenger and freight traffic is assigned to the network using a stochastic user equilibrium assignment operating for 24 hours. It does not separate out traffic by time of day.

Following sections discuss the passenger and freight categories in SCENES and the Network specifications.

3.9.2.1 Passenger categories

The passenger trip purposes are listed in Table 1, and the corresponding main passenger modes are listed in Table 2. Modal stages, such as ferries used in the course of a car trip, are explicitly distinguished as a part of the main mode in which they occur.

Table 1: Passenger travel purposes

Commuting & business, all population groups / no car available
Commuting & business, all population groups / part car available
Commuting & business, all population groups / full car available
Shopping / personal business / education / visits / day trip, children / all car availability groups
Shopping / personal business / education / visits / day trip, all >15 / no car available
Shopping / personal business / education / visits / day trip, all >15 / part car available
Shopping / personal business / education / visits / day trip, all >15 / full car available
Visiting friends and relatives / day trip / other, all population groups / no car available
Visiting friends and relatives / day trip / other, all population groups / part & full car available
Commuting and business long, all groups
International business (1+ night), all groups
Domestic holidays, all population groups / no car availability
Domestic holidays, all population groups / part & full car availability
International holidays, all population groups / no car availability
International holidays, all population groups / part & full car availability

Table 2: Main passenger modes

car
business car
local bus
long distance coach
train (business and standard class),
high speed train
air (business and leisure)

3.9.2.2 Freight categories

Ten main modes of transport are implemented for freight:

- large articulated trucks, smaller rigid trucks
- bulk rail, container rail, shuttle container rail
- bulk ship, container ship,
- bulk waterway, container waterway,
- product pipelines.

Each mode is available to a set of 13 separate flow types (listed in Table 3), according to its specific features with respect to the nature of the flow. These are grouped into four handling categories with homogeneous requirements:

- Solid bulk
- Liquid bulk
- General Cargo
- Unitised freight

Modal split for freight is performed for each flow type individually using a multinominal nested logit model. The nested logit has three different level of choice:

- the first choice is between land modes and other modes (shipping and pipeline);

- the second choice is among land modes (rail, barge and truck);
- the third one, at the lowest level, is between the large and smaller trucks.

Modal stages, such as ferries used in the course of a truck or rail movement, are explicitly distinguished as a part of the main mode in which they occur.

Table 3: SCENES freight flows compared with standard freight categories

Flow	NST/R group	Group of Goods	Handling category
1- Cereals and agricultural products	00 01 04 05 06 09 17 18	1 3 4 5 part of 6 7	General cargo
2 – Consumer food	02 11 12 13 16	Part of 2 Part of 6	Unitised
3 – Conditioned food	03 14	Part of 2 Part of 6	Unitised
4 – Solid fuels and ores	21 22 23 41 45 46	8 11 12	Solid Bulk
5 – Petroleum products	32 33 34	10	Liquid Bulk
6 – Metal products	51 52 53 54 55 56	13	General Cargo
7 – Cement and manuf. building mat.	64 69	14	Unitised
8 – Crude building materials	61 62 63 65	15	Solid Bulk
9 – Basic chemicals	81 83	17 part of 18	Solid Bulk
10 – Fertiliser, plastic and other chemicals	71 72 82 84 89	16 part of 18 19	General Cargo
11 – Large machinery	91 92 939	part of 20	General Cargo
12 – Small machinery	931	part of 20	Unitised
13 – Miscellaneous manufactured articles	94 95 96 97 99	21 22 23 24	Unitised

3.9.2.3 Link types

The SCENES model has a conventional link based representation of the supply of transport on all passenger and freight transport modes across Europe. It has over 600 different link types, all of which enable distinctions to be made between different network mode and origin countries. The main link classification categories within each modal network are:

- The Road network consists of four basic classes – Tolled motorway, motorway, dual carriageway and other road.
- Rail links can be divided into Conventional or High-speed, and Domestic or International and for Rail freight links it is additionally possible to distinguish Bulk Freight from other freight links.
- Air links are divided into Domestic and International categories. There is also an additional link type for chartered flights.
- Inland Waterways are divided into Rivers, Canals and Canal/River.
- Shipping links and ports are separated into deep sea shipping and coastal shipping and the loaded and unloaded tons are also classified for each port according to the handling categories: liquid bulk (e.g., crude oil, petroleum products, and liquefied gas), solid bulk (e.g., cereals, carbons, iron ore), General Cargo (Semi Bulk/Ro-Ro) and Unitised (ie container transhipments).
- Pipelines are used for liquid bulk products.

The transport network is mainly extracted from the detailed GIS network developed by IRPUD at Dortmund University.

The model uses a two level description for transport modes. At the individual link level, the movement of a passenger or unit of freight is represented by a *network mode* related to the link type. Network modes correspond generally to the vehicles and vessels on the line haul, and the handling operations at transfer and transhipment sites. At the level of a complete trip, movements of passengers and freight are represented by a *user mode*.

Each user mode is built up as a collection of network modes, in accordance with the actual stages of travel. The user modes are usually named after the main line haul mode but often include a number of auxiliary network modes. A passenger or freight movement is qualified to be of a specific user mode provided that it uses the designated main network mode for more than a minimum proportion of the journey. For example, flows fed by lorry into coastal shipping have coastal shipping as their main network mode, lorry being a feeder mode.

Inter-modal freight trips involving the use of various modes at different stages, can be represented unambiguously in terms of their main mode, by defining a hierarchy of main modes. Among the modes that it uses, a shipment is said to belong to that mode which lies highest in the main mode hierarchy.

3.9.3 Calibration

The model is calibrated to reproduce (as closely as possible) national aggregate totals of travel by mode, and known international patterns of passenger and freight transport. The sub-national pattern of passenger and freight traffic is entirely generated by the model (i.e., it is ‘synthetic’). It is based on typical distributions of travel by distance.

For the 1995 base year, the passenger model is built up from the zonal level using demographic and socio-economic population groups, together with detailed trip rate data by purpose. At each stage of the modelling process, through Generation – Distribution – Modal Split - Assignment, the level of aggregation of population group and of trip purpose increases, starting from a highly disaggregate structure.

The model reproduces the following known general characteristics of passenger travel:

- Number of trips per person (per day / year) by purpose, over different distance ranges,
- Number of trips by mode (car, bus, rail, non-mechanised, and air),
- Number of international ‘tourism’ trips, by country pair,
- Modal share over different distance ranges.

At the aggregate level, the main validation factor is person kilometres travelled by mode (car, bus, train, air) by country. The freight calibration is similarly structured with the main validation factor being the tonne kilometres moved by mode per country.

3.9.4 The TREMOVE baseline scenario for 2020

The forecast scenario used in 2020 was based as far as possible on same assumptions as the CAFE baseline, using the same assumptions as the PRIMES model "without climate policies" base case. This included:

- Overall national GDP growth to 2020
- Total national population in 2020

Because SCENES requires finer geographic detail than PRIMES, an existing SCENES 2020 scenario was adjusted to match PRIMES growth rates by country.

3.9.4.1 Future tariffs

Assumptions about future trends in transport tariffs are an important input to a future year SCENES run. The TREMOVE baseline assumption for 2020 was of *constant cost* for non-rail modes, that is, that the tariffs remain constant in real terms. (All monetary values in SCENES are in real terms). There was no consensus amongst those advising TREMOVE in favour of any alternative scenario. Moreover, it is consistent with the historic trend in car and truck operating costs where increases in fuel prices have been approximately offset by increases in engine efficiency and more efficient logistics. Other modes are also subject in their own ways to competing trends, with more expensive fuel and wages offset by technological and business improvements.

There was some consensus that rail freight is likely to become more expensive between 1995 and 2020, supported by the current trend in some countries. In agreement with DG-Environment, the TIPMAC project's figure of 1.5% growth in real tariffs per year was adopted, and leads to 4% drop in rail tonne-km in the EU-15 between 1995 and 2020 despite the coincident economic growth. The constant-cost assumption in Lot 1 had resulted in a doubling of rail tonne-km over the 25 years.

There was also consensus that passenger rail fares were likely to rise, though it was less clear how great this increase would be. Applying the TIPMAC figure of 1% growth per annum led to the greatest increase in fares in countries that already have high fares such as the UK and Germany, with a consequent drop in rail patronage in those countries that seems unlikely.

We argue that the growth in fares is likely to be greatest in those countries that have relatively lower fares (and higher subsidies to rail) in 1995, rather than in high fare countries such as the UK that have restructured their railways and reduced state subsidy. Therefore, the baseline scenario makes the fares more homogeneous by bringing most countries' fares halfway up from their present level towards the level of the German fares in the base year. This is not an assumption about the removal of subsidies as such, but a general observation about the evolution of passenger rail in European nations. The overall impact of this was a 17% growth in passenger-km over the 25 years in the EU-15, versus 32% in the Lot 1 constant-cost scenario, but this varied considerably by country.

3.9.4.2 Vehicle occupancies and truck loading factors

Calibration of SCENES has focused on passenger and tonne kilometres rather than vehicle-km, largely because the available data is better. Good national data about vehicle occupancies *by trip purpose* is difficult to come by. The standard SCENES numbers are retained. These were derived from the UK National Travel Survey. Note that average occupancies from SCENES-TREMOVE are distance weighted, so that long distance car journeys that have higher occupancy have a greater weight than commuting trips. These averages will therefore tend to be higher than statistics for average occupancies per trip.

The assignment unit for freight is a tonne for each mode except for road transport. For road, the number of truck vehicles corresponding to a certain level of road traffic (expressed in tons) is obtained by means of suitable load factors for each type of commodity on each of the vehicle sizes.

SCENES truck loading factors exist to produce vehicle-km following the division of tonnes between heavy and medium truck modes. While this division has been broadly described as around the 12 tonnes gross weight, it is not as precise as that because the mode split calibration data did not support it. These two modes of smaller and large trucks exist to represent some of the heterogeneity in road freight operations, not to represent particular vehicle classes in detail.

Unfortunately these classes do not exactly match the TREMOVE demand tree's large and small truck modes, let alone the finer grades required in the vehicle stock module. The SCENES classes are nevertheless passed through unfiltered. This is an important area where integration between the two models could be improved in subsequent work.

3.9.4.3 Network speeds

Non-road modes do not experience congestion in the SCENES model and use speeds derived in the original SCENES work. These are average journey times rather than peak vehicle speeds. They are reported directly to TREMOVE.

The road network has some free-flow speeds by road type and country that are also reported. However, because intrazonal traffic is not assigned to the road network it is not possible to work out the congested speeds entirely from the free-flow speeds and loads. Therefore the free-flow speeds are reduced to "congested speeds" in advance of the road assignment based on a banding of the traffic density in the zone (total vehicle-km/surface area) which tends to give larger reductions in predominantly urban zones.

The road speeds are then subject to a "marginal capacity restraint" calculation where each road type and zone density band has an elasticity and maximum change of time with respect to load.

This method was used to inform TREMOVE speed-flow curves for non-urban traffic, by adding some extra load and observing the change in average speed.

3.9.4.4 Car ownership

Car ownership is an exogenous input expressed in cars per 1000 head of population in each zone. Table 4 shows European car ownership in 1995 and 2000 from Eurostat Transport in Figures (TIF) 2003, along with the 2020 forecasts used in SCENES for TREMOVE. The SCENES model uses these TIF figures for the 1995 model.
The EU15 growth rates were derived from trends in car ownership growth from TIF historical data. Earlier work during the development of the SCENES model (DG TREN SCENES project) by the SCENES consortium had allowed the estimation of individual zonal car ownerships. The Accession country growth rates were also estimated by the Consortium on the SCENES project although some

minor adjustments were made during the TREMOVE project. Additionally, the TREMOVE member states were asked for up to date car ownership forecasts for the baseline scenario in 2020. The data that was supplied was used to update SCENES car ownership. Member state forecasts that gave absolute numbers of vehicles were converted to rates for use with the SCENES/PRIMES population forecasts.

The last column of Table 4 shows the data source : consortium estimates are input from the countries.

Table 4: Car ownership in SCENES (cars per 1000 population)

Country	Eurostat TiF		SCENES	
	1995	2000	2020	Source
Austria	447	506	672	Member state contribution (Umweltbundesamt)
Belgium	422	458	532	SCENES estimate
Czech Republic	295		455	SCENES estimate
Germany	495	521	566	SCENES estimate
Denmark	319	347	359	Member state contribution, via Ministry of Environment
Spain	362	442	552	SCENES estimate
Finland	372	413	501	Finnish road administration
France	422	463	515	SES (Econ. and Statistics Service)
Greece	211	304	457	SCENES estimate
Hungary	225		410	SCENES estimate
Ireland	265	343	491	National Roads Authority[14]
Italy	529	563	678	SCENES estimate
Luxembourg	559	623	682	SCENES estimate
The Netherlands	364	411	520	SCENES estimate
Poland	194		442	Member state forecast excluding LDV
Portugal	258	350	410	SCENES estimate
Sweden	411	451	542	SCENES estimate
Slovenia	357		506	SCENES estimate
United Kingdom	374	419	566	UK Department for Transport

3.9.4.5 Future Networks

The future year network that was used included national infrastructure schemes already underway or planned together with the TENs projects listed in Table 5.

Table 5: TEN projects included within the future year network for 2020

Project
1) High Speed train/combined transport North-South: Germany, Austria, Italy
Add to 1) Milan-Bologna and Verona-Naples
2) Paris –Brussels-Köln/Frankfurt- Amsterdam-London (PBKAL)
3) High Speed Train South: France, Spain
Add to 3) High speed rail South, Montpellier-Nîmes
4) HST Paris eastern France- south-western Germany (TGV Est)
5) Betuwe dedicated freight rail line: Netherlands
6) High Speed Train / Combined Transport - Lyon-Turin-Trieste
7) Greek Motorways (PHATE / Egnatia)
8) Multimodal link: Portugal-Spain – Europe
9) Conventional rail link: Cork-Dublin-Belfast-Larne-Stranraer (completed)
10) Malpensa Airport, Ireland (completed)
11) Öresund Fixed road/rail Link: Denmark, Sweden (completed)

[14] http://www.nra.ie/Transportation/DownloadableDocumentation/d1183.PDF

Project
12) Nordic Triangle Multimodal corridor
13) Ireland-UK-Benelux road link
14) UK West Coast Main Line (rail)
15) Global navigation & positioning system, Galileo
16) High-capacity rail Pyrenees crossing
17) East-west rail link: Stuttgart-Munich-Salzburg-Vienna
18) Danube river improvements: Vilshofen-Straubing
19) Interoperability of Iberian high-speed rail network
20) Fehmarn fixed link: Germany, Denmark

3.9.4.6 Values of Time

Passenger and freight Values of Time are inputs to SCENES, used to determine path choice and overall transport disutilities. These come from a variety of sources as detailed in SCENES Deliverable 4, and vary by country, main mode and flow (purpose or goods type). The values reported for TREMOVE are averages in the base year 1995, based on the actual pattern of movement in the model corresponding to the TREMOVE leaf node.

3.10 Post-Processing of SCENES Results for TREMOVE

3.10.1 Overview of TREMOVE requirements

The most important data tables that SCENES supplies to TREMOVE are the flow quantity (tonne-km or passenger-km), vehicle-km, and unit cost, for each appropriate leaf node of the demand CES tree. This is done for each country and for both 1995 and 2020 model results.

The TREMOVE tree branches on geography, purpose and type of movement, mode of transport, and type of network (motorway versus other roads). Because SCENES definitions and model scope do not match this tree perfectly, the SCENES results are assigned to leaf nodes by a post-processing operation. The following sub-sections describe the way that quantities of travel are split at each of the nodes of the tree.

3.10.2 Geography

TREMOVE divides each country into at most three regions: metropolitan, other urban, and non-urban. The refinement of the corresponding urban versus non-urban classification in SCENES post-processing is one of the recent improvements.

SCENES uses 1998 NUTS II zones within the EU-15, and in the CEEC countries uses statistical regions of similar scale, as they were defined in 1995. There are a few NUTS II zones that are further subdivided in Ireland and Denmark.

In many countries, the SCENES zones are large and a zone containing a city such as Madrid can also include a great deal of non-urban land and transport activity. For this project, we defined a set of “micro zones” within the main zones covering the whole TREMOVE study area. These micro-zones were the basis of the urban classification. Each micro zone is assigned the transport activity happening on networks over its territory. That is, the increase in spatial detail is based on the

SCENES network assignment, combined with the population analysis described below for intrazonal movements.

The micro-zones were the NUTS III regions in the EU-15, Hungary and the Czech Republic. For technical reasons, the micro-zones in Poland were just the SCENES NUTS II zones. Cantons were used for Switzerland's micro zones. In Slovenia and Norway, the SCENES road and rail networks were too sparse to use smaller micro zones, so the micro-zones are the whole-country SCENES zones.

Each micro-zone was assigned a total population for the year 2001 based on Eurostat's Regio data or other sources (the Swiss Federal Statistical Office, Statistics Norway, and the Slovenian report for TREMOVE). This was corrected for NUTS III boundary changes between 1998 and 2001.

A list of European cities with their population was obtained from a reasonably consistent source (www.citypopulation.de) and combined with a city location map. Each micro zone was then assigned an "urban population" equal to the sum of the populations of cities in the zone of more than a certain number of inhabitants. The actual threshold varies by country, based on what was available in the data to which we had access. For example, the number of cities in the UK over 100 000 inhabitants is quite large and geographic identification of cities between 50 000 and 100 000 was not feasible in the time available.

Note that this data attempts to consider urban agglomerations together, rather than using the municipal administrative boundaries.

Table 6: Urban and metropolitan definition by country

Country	Metropolitan area	Urban settlement size threshold	Number of settlements
Austria	Vienna	50 000	13
Belgium	Brussels	75 000	16 (Brussels communities counted as 1)
Czech Republic	Prague	50 000	22
Denmark	Copenhagen	50 000	7
Finland	Helsinki	50 000	12
France	Paris	50 000	111
Germany	Berlin	50 000	148
Greece	Athens	50 000	14
Hungary	Budapest	75 000	11
Ireland	Dublin	75 000	3
Italy	Rome	50 000	38
Luxembourg	none	Luxembourg	1
The Netherlands	Randstad	100 000	23
Norway	Oslo	50 000	n/a (aggregate total)
Poland	Warsaw	250 000	13 (urban aggregates)
Portugal	Lisbon	50 000	6 (Lisboa counted once but assigned to multiple micro-zones)
Slovenia	none	Ljubljana	1
Spain	Madrid	250 000	20
Sweden	Stockholm	75 000	19
Switzerland	Zürich	50 000	12
United Kingdom	London	100 000	70

The fraction of the population in each micro-zone living in these cities is then defined as

$$p_{urban}[mz] = \frac{\sum citypop}{total\ population}$$

In some cases the city population was larger than the total population, because the city population measures an agglomeration larger than the central zone. In these cases the extra city population was allowed to "overflow" to neighbouring micro-zones so that p_{urban} was never greater than 1.0. For example, the Inner and Outer London micro-zones were considered 100% urban and some population still overflowed to the Home Counties.

Each micro-zone was defined as "metropolitan" or "other urban", which determines which TREMOVE region the urban proportion was accounted to. Initially the metropolitan area was taken to be all micro-zones within the SCENES/NUTS II zone containing the designated metropolitan city of Table 6, but this classification was adjusted by hand where that zone was very large.

The following countries were treated differently:

- Norway as a single zone used an overall national three-way split between metropolitan/other urban/non-urban population, based on data from Statistics Norway.
- Slovenia as a single zone without a metropolitan area used the urban/non-urban split defined in the Slovenian report for TREMOVE, which defined Ljubljana as the urban area.
- Luxembourg as a single zone without a metropolitan area used the Luxembourg district as the urban area.

The outcome of this procedure was three proportions for each zone such that

$$p_{metrop}[mz] + p_{other\ urban}[mz] + p_{non-urban}[mz] = 1$$

3.10.3 Assigning transport model results to geography

The main results file from SCENES that is used lists the flow volume, cost, motorway toll, time, and distance for each link in the transport network, including road, rail, waterway, non-mechanised mode and intrazonal movements. These are subdivided by mode of transport, flow (the type of freight commodity or of passenger purpose) and distance band. The bands chosen were: "short" trips of 0 to 50 km, "medium" trips of 50 to 500 km, and "long" trips of over 500 km. Motorways can be distinguished from other kinds of road.

Each inter-zonal link has a geographic location and its traffic was assigned to one or more micro-zones that it overlapped. For example, a 10 km link with 4 km in micro-zone A and 6 km in micro-zone B would contribute 40% of its vehicle-km and tonne-km to A and the remaining 60% to B. Total quantities are therefore preserved.

Now suppose zone A was classified as 80% metropolitan and 20% non-urban, while B was counted as 50% other urban and 50% non-urban, and that they are in the same country. The link tonne-km will then have contributed via zone A, 80%*40%=32% to the TREMOVE metropolitan zone for the country, via zone B 50%*60%=30% to the "other urban" zone, and 20%*40%+50%*60%=38% to the non-urban zone. Vehicle-hours are also tallied in order to calculate average speeds.

This scheme was modified in the following circumstances:

- journeys over 50 km and inter-zonal rail journeys were considered non-urban along their entire length
- rail and waterway freight were always non-urban

- passenger air transport was always non-urban and was attributed by origin and destination of travel (one table of each), not by geographic route

Intrazonal movements were not assigned to the main road, rail or waterway networks but appear on separate intrazonal links representing distance bands within the zone. For example, a zone of diameter 50 km would have three intrazonal road links representing 0-10 km, 10-25 km, and 25-50 km. It may also have intrazonal rail and/or waterway links for those bands as appropriate to the zone.

Intrazonal trips by passenger train, car, non-mechanised modes, bus, and road freight were subdivided by area type using the proportions $p_{non\text{-}urban}$ etc. on the grounds that local passenger and freight trip generation is related to population. If 20% of the population lived in "other urban" areas, 20% of intrazonal car trips would have been considered "other urban".

Intrazonal passenger rail does not distinguish between non-urban rail, urban/suburban standard rail, metro, and tram. Eurostat Transport in Figures (TiF) provides separate measures of billion passenger-km per year (GPkm/year) by country for standard rail, metro and tram systems but does not distinguish the urban component of standard rail that the TREMOVE categories need to include in the urban and metropolitan trees. This was determined as far as possible from other data sources as shown in Table 7 and the SCENES urban vs. non-urban train split is adjusted at the country level to match these proportions. This means the train split between metropolitan and other urban was still roughly related to the relative populations and the usage of intrazonal train in the respective areas.

Table 7: Urban/non-urban passenger rail split applied in post-processing

Country	TiF (GPkm/year)			TREMOVE Urban rail (std. rail urban+tram+metro)				Sources
	Std. rail	metro+ tram	total	% of total	GPkm/ year	of which metro	tram	
Austria	9,6	2,6	12,2	61%	7,5	34%	0%	German figure
Belgium	6,8	0,8	7,6	55%	4,2	19%	0%	Benelux figure
Czech R.	8,0	no data	8,0	41%	3,3	0%	0%	ETiF 2003, EU-15 avg split
Denmark	4,8	0,0	4,8	27%	1,3	0%	0%	National statistics
Finland	3,2	0,4	3,6	11%	0,4	100%	0%	No data on urban std. rail
France	55,3	8,3	63,6	29%	18,5	43%	2%	RER + Transilien
Germany	75,0	14,4	89,4	59%	52,9	27%	0%	National transport stats.
Greece	1,6	0,7	2,3	32%	0,7	100%	0%	No data on urban std. rail
Hungary	8,4	no data	8,4	41%	3,4	0%	0%	ETiF 2003, EU-15 avg split
Ireland	1,3	-	1,3	28%	0,4	83%	0%	National statistics
Italy	43,9	5,2	49,1	48%	23,5	22%	0%	National statistics, regionale v. long distance
Luxembourg	0,3	-	0,3	50%	0,2	0%	0%	Benelux figure
Netherlands	14,0	1,4	15,4	54%	8,4	16%	0%	Benelux figure
Norway	2,3	0,4	2,7	15%	2,7	0%	0%	Transport Econ & Stats. Metro % not reported.
Poland	26,6	no data	26,6	41%	10,9	0%	0%	ETiF 2003, EU-15 avg split
Portugal	4,8	0,5	5,3	50%	2,6	20%	0%	National statistics
Slovenia	0,6	no data	0,6	41%	0,2	0%	0%	ETiF 2003, EU-15 avg split
Spain	16,6	4,3	20,9	55%	11,6	37%	0%	National statistics
Sweden	6,3	1,9	8,2	80%	6,6	23%	6%	National statistics
Switzerland	11,7	2,2	13,9	58%	8,09	27%	0%	Swiss FSO, assuming std. rail is 50% urban
UK	30,2	6,8	37,0	54%	20,1	34%	0%	National stats, std. urban=Network SE 1995

Within the urban train, the metro and tram volumes are reported separately using a fixed proportion per country, based on Transport in Figures values for metro passenger-km in the base year. Inadequate data about tram systems mean that SCENES reports no tram activity in most countries, even those such as Belgium that did have tram systems in 1995.

For the 4 eastern European countries, metro numbers were not readily available, and the average urban % of the EU-15 (41%) has been applied to the passenger-km total.

The distinction between urban and non-urban rail in Belgium and The Netherlands presents a definitional difficulty. 50% of the standard rail was deemed to be urban, along with all the metro activity, and this was also used for Luxembourg where there was no other split data.

3.10.4 Trip purpose and type of goods

After the geographical division, the next main division is between non-working trips (TREMOVE code *PCN*), commuting trips (*PLC*), business trips (*BNT*) and freight trips (*BFT*). These divisions are made by SCENES *flow type*: flows 1-13 are freight (*BFT*); flows 20 (business trips) and 21 (business international trips) are assigned to *BNT*, commuting flows 26-28 are assigned to *PCN*, and the remaining passenger flows are non-working (*PCN*). SCENES does not model TREMOVE's "Other" categories (*PCO, PLO, BNO, BFO*). There is a good match between SCENES and TREMOVE definitions, so no additional assumptions were required to define this match.

Freight trips are further divided in the *non-urban freight* lower tree using SCENES flow numbers, the categories being:

- Bulk (*FNB*): Fuels, ores, petroleum products, crude building materials, basic chemicals
- non-bulk Cargo (*FNNC*): Cereals, agricultural products, metal products, plastics & chemicals, large machinery.
- non-bulk Unitised (*FNNU*): Food, cement and manufactured building materials, small machinery and miscellaneous articles

3.10.5 Mode split

Table 8 below shows the correspondence between SCENES and TREMOVE modes, including the urban definition. In each row one or more SCENES modes are combined together and then divided into one or more TREMOVE flows based on the flow type and the urban/non-urban methodology described above. The special treatment of passenger car and train modes is detailed below.

Table 8: Correspondence of modes between SCENES and TREMOVE

SCENES modes	TREMOVE modes	TREMOVE code	Notes
passenger train, high-speed train	urban train & metro non-urban train	TUNT TNNNT	split as in section 3.10.3
bus, coach	urban bus non-urban coach	TUNB TNNB	split by region
Air	air	TNNNP	
non-mechanised	urban non-mechanised non-urban non-mechanised	TUPNS TNPNS	split by region

SCENES modes	TREMOVE modes	TREMOVE code	Notes
car, business car, *estimate of* *LDV (vans < 3.5t)*	big car/LDV urban small car urban motorcycle urban big car/LDV non-urban small car non-urban motorcycle non-urban	TUPCB TUPCS TUPNM TNPCB TNPCS TNPNM	see 3.10.5
HGV (heavy truck)	truck large urban truck large bulk NU truck large cargo NU truck large unitised NU	FUL FNBTL FNNCTL FNNUTL	split by flow type and region
medium truck (= 3,5 ton), *estimate of* *LDV (< 3,5 ton)*	truck small urban truck small bulk NU truck small cargo NU truck small unitised NU	FUS FNBTS FNNCTS FNNUTS	split by flow type and region
bulk waterway, unitised waterway	waterway, bulk waterway, cargo waterway, unitised	FNBNI FNNCNI FNNUNI	split by flow type
bulk rail freight, unitised rail freight	rail freight, bulk rail freight, cargo rail freight, unitised	FNBNT FNNCNT FNNUNT	split by flow type

The “car” mode in SCENES is a combination of all sizes of car as well as motorcycles. This was first split between motorcycle (including moped) and car using a fixed proportion of passenger-km by country from Eurostat Transport in Figures. Motorcycles were assumed to have an average occupancy of 1,1 based on UK research, and the remaining vehicle-kms were attributed to cars.

These car passenger-km and vehicle-km were further split by vehicle size using a fixed proportion by country using vehicle-km data from the TRENDS project. The overall 3-way split of passenger-km is shown in Table 9 below.

This table also shows the proportion of total motorcycle-kms that is considered to be on mopeds, also based on TRENDS data. Mopeds are reported separately from the main demand tree. It is assumed that mopeds do not make long (> 500 km) journeys or use motorways, so the post-processing calculates a fixed proportion per country of all the TREMOVE short, non-motorway motorcycle leaf nodes such that the total vehicle-km split matches that below.

Table 9: Car passenger-km split by country

Country	Motorcycle M/C (%)	Small Car (%)	Big Car (%)	Moped within M/C (%)
Austria	2,3	32,8	64,9	55
Belgium	1,4	19,4	79,2	45
Czech Rep	8,8	70,9	20,3	71
Denmark	0,7	54,6	44,7	49
Finland	1,8	51,7	46,5	36
France	1,9	38,7	59,4	39
Germany	1,7	25,1	73,2	27
Greece	18,3	63,5	18,2	45
Hungary	8,8	70,9	20,3	71
Ireland	1,3	64,9	33,8	39
Italy	8,9	51,2	39,9	54
Luxembourg	1,3	32,7	66,1	44
The Netherlands	1,6	42,6	55,8	43
Norway	1,6	27,5	70,9	45

Country	Motorcycle M/C (%)	Small Car (%)	Big Car (%)	Moped within M/C (%)
Poland	8,9	70,9	20,3	71
Portugal	7,7	51,2	41,1	71
Slovenia	8,7	71,0	20,3	71
Spain	5,0	47,8	47,2	50
Sweden	0,7	27,8	71,5	45
Switzerland	3,1	32,6	64,3	55
UK	0,7	41,0	58,3	19

LDVs (light duty vehicles, ie. vans of less than 3,5 tonnes) are not modelled in SCENES because of the absence of suitable data on which to implement the model. Instead the LDV vehicle-km are estimated as a fixed proportion by country of the total vehicle-km of trucks over 3,5 tonnes, and a fixed proportion of these are added on to the appropriate big car and small truck modes. These ratios come from the TRENDS project. Freight LDVs are assumed to have a net load of 0,8 tonnes. LDV vehicle-km are also reported separately.

Table 10: TRENDS based ratio of LDV vehicle-km to larger truck vehicle-km

Country	LDV veh-km / HDV veh-km
Austria	16%
Belgium	66%
Czech Rep	87%
Denmark	54%
Finland	103%
France	193%
Germany	36%
Greece	162%
Hungary	87%
Ireland	51%
Italy	76%
Luxembourg	27%
The Netherlands	1%
Norway	110%
Poland	87%
Portugal	63%
Slovenia	87%
Spain	237%
Sweden	110%
Switzerland	16%
UK	112%

3.10.6 Peak/off-peak split methodology

SCENES is an "all-day" model of a typical day with no peak information in the model itself. TREMOVE defines a peak period as 6 hours during each of 240 working days per year, 7 am – 10 am and 4 pm – 7 pm. Each leaf of the upper demand tree is divided into peak and off-peak travel using a set of proportions:

pk(flow, distance band, TREMOVE mode, TREMOVE zone type)

where *flow* is one of freight, business, commuting or non-work; distance band is 0-50 km, 50-500 km, or 500+ km; and TREMOVE zone type is one of metropolitan, other urban, or non-urban.

The peak volume is the annual volume times *pk*, whereas the off-peak volume is the annual volume times *(1-pk)*, so total volume is conserved. Tonne-km, passenger-km, vehicle-km, vehicle-hours and tolls are treated analogously; the speed effect of peak congestion is modelled within TREMOVE itself using speed-flow functions, but cannot be treated within SCENES.

These peak proportions were developed from previous UK modelling research, especially the UK National Travel Survey for passenger travel.

3.10.7 Zone-based speed-flow functions

The construction of speed-flow functions based on SCENES comprises the search for peak and off-peak speeds in the TREMOVE zones and the constructing of the functional form. The two aspects are discussed.

3.10.7.1 Peak and off-peak speeds

The speed-flow functions work on a base time. Therefore travel time for the different countries and the different zones is a required input. The SCENES model cannot provide this input because it deals with daily traffic whereas TREMOVE need peak and off-peak travel time. Additional data is required.
In order to appraise peak and off-peak average speed in different zone types evidence on road speed in different time periods of the day have been used. Two kinds of data was available:

- average speed by hour over a 24 hour period from Italian traffic counts on a sample of roads of different type (urban, rural, etc.);
- British data concerning average speed in off-peak, morning peak and evening peak in different contexts: urban roads, motorways, London roads, etc.

Using this kind of data, the following ratios have been computed:

- peak speed / average daily speed;
- off-peak speed / average daily speed,

The same ratios have been computed from the British data. This data does not refer to single counts but it is already an average of several counts, so in principle it has a wider validity. Fortunately, the two sources compare quite well. From the British data ratios for a metropolitan area (London) could be computed and also more representative figures for motorways could be estimated.

The final outcome of the estimation is reported in the table below[15].

Table 11: Ratios between peak and off-peak speed and average speed

	Average speed	Peak speed	Off-peak speed
Metropolitan	1,00	0,94	1,06
Urban	1,00	0,94	1,10
Motorway	1,00	0,99	1,06
Other roads	1,00	0,98	1,03

As expected, the largest difference results for urban roads, while for motorways and rural roads the difference is smaller[16].

15 Source: TRT on Italian and UK traffic counts data.

The ratios in Table 11 provide a method to appraise average peak and off-peak speed when average daily speed is known. SCENES data includes this information for each country over the whole period 1995 - 2020. Therefore, by applying the ratios to the country data, peak and off-peak average speeds for each country have been estimated[17].

3.10.7.2 Congestion function

The estimation of zone-based speed-flow functions for the TREMOVE model has been based on the SCENES network model. SCENES provides demand data to TREMOVE and therefore it is consistent to use it.

The approach is as follows. Being a network model, the SCENES model includes link-based speed-flow functions[18]. From these functions, known the link loads at the base year, it can be readily computed the effect on travel time of a given increment of traffic on the links. More specifically, for a given link *l*, and a given demand *d* travel time is computed as:

$$Time_{ld} = BaseTime_l \left(0.75 + \frac{0.5}{1 + e^{-ParB(r_{ld} - 1)}} \right) \qquad [1]$$

Where:

ParB depends on the link type (motorway, dual carriageway road, etc.) and

r_{ld} is the ration between current load (*d*) and base load

In order to aggregate this information, a weighted average can be computed where the weight is the base load of each link:

$$ZoneTime_d = \frac{\sum_l Time_{ld} * Load_l}{\sum_l Load_l} \qquad [2]$$

By repeating the procedure for several levels of demand, various travel times can be plotted. An interpolation of such points allows to estimate a relationship between demand and average zone time, i.e. the zone-based function.

Figure 11 shows an example of the outcome of this method. For sake of generality, both demand and travel time are expressed as ratio with respect to the base. For instance, according to the function in

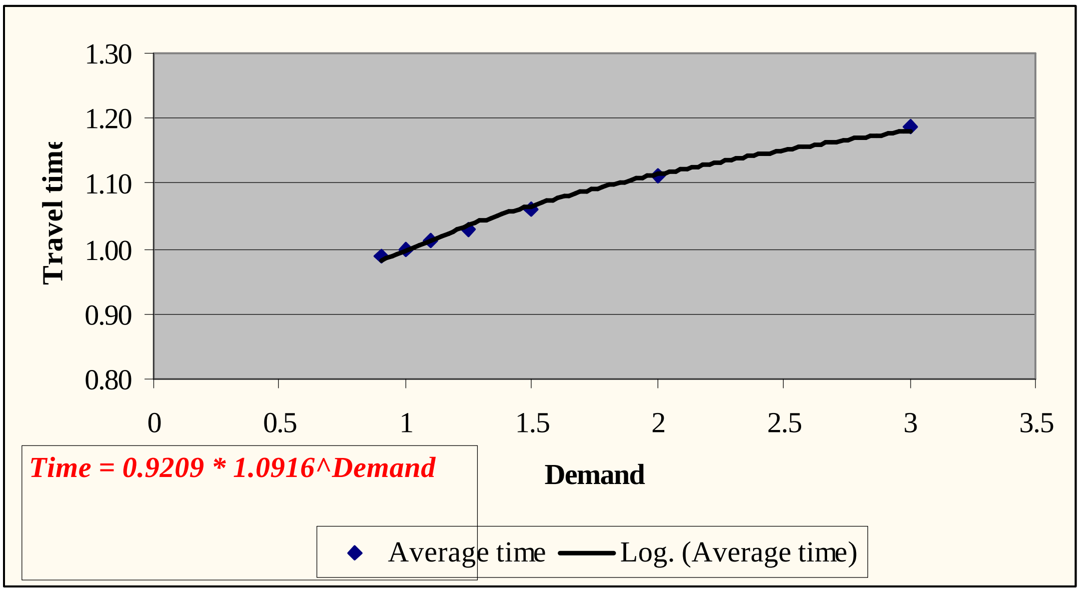
[16] In very congested areas, average speed on motorways can fall much below under the off-peak speed. However, TREMOVE requires data which is representative of the average conditions at the country level. In this respect the results of the estimation looks reasonable.

[17] This method assumes implicitly that the ratios computed on the Italian data have a general validity for all countries. One would need additional data from other countries to verify this simplifying assumption. If new evidence is found the assumption could be relaxed in the future.

[18] SCENES speed-flow functions are of a special type. SCENES is a strategic European wide model, whose network include just a set of the existing roads. In some cases a link may be thought of as representing a section of the network, rather than a particular stretch of a specific road. Furthemore, part of the traffic (short intrazonal trips) is not assigned on the network. For that reason, link-based speed-flow functions are specifically studied in order to work consistently with the level of detail of the model.

figure, increasing demand of 25%[19] with respect to the base case (demand = 1,25) gives rise to an increment of average travel time of 3% (travel time = 1,03).

Figure 11: Example of interpolation of zone travel time under different demand levels



This approach has been used to estimate zone-based speed-flow functions for each of the country included in the TREMOVE model. For each country three different functions have been computed

3.10.8 Tariffs and costs

Tariffs are calculated as an overall average of the end-to-end cost of trips divided by the tonne-km or passenger-km. This is necessary because the full costs of modes such as rail passenger or freight do not show up at the network level in SCENES but also include elements that are coded separately at the start and end of the trips.

These tariffs are an average output of the model, rather than simply being inputs. Therefore, an increase in unit cost may be the result of a change in travel patterns without necessarily resulting from a change in input tariff assumptions.

The "network toll" results reported are solely revenue from motorway tolls in those countries that have them. Border effects may sometimes lead to a small leakage to adjoining countries. SCENES does not include the London congestion charge nor similar schemes covering small urban areas, within the future scenario.

3.10.9 Evolution between 1995 and 2020

Unit costs, speeds, and populations are interpolated between 1995 and 2020 using a constant growth assumption per leaf node independent of other leaf nodes. Vehicle and flow quantities for are interpolated as piecewise constant growth between 1995 and 2000, and between 2000 and 2020, where the year 2000 value is the 1995 value scaled by mode so that the aggregate totals match Eurostat Transport in Figures for the year 2000. This presents a more accurate trend over the 1995-2000

[19] The simulations have been carried out under the simplifying assumption that demand changes of the same amount on each link.

period, where this data is available. While 2002 was originally considered as an interpolation year instead, consistent data was not yet available for all the countries involved, so this was not pursued further.

Passenger air travel is not treated this way, because Transport in Figures does not provide air travel numbers. No interpolation through a year 2000 value is made and the quantities of trips and passenger-kms are interpolated using a constant growth from 1995-2020 in the same way as the unit costs.

3.10.10 Donor countries

SCENES does not model freight between CEEC countries or within Switzerland or Norway, only freight between the CEEC and the EU15. Neither does it model all passenger movements within Switzerland or Norway, but only movements to or from EU15 countries. Therefore it was not possible to provide comprehensive data from those countries directly. Instead a "donor country" approach was taken, so for example in Norway the results for Sweden plus Norway are scaled down to fit the known total volumes for Norway. This is the best solution that could be implemented within the constraints of the current model.

Table 12: Results "donor" countries

Donor country	Type	Recipient country
Sweden	Passengers and freight	Norway
Austria	Passengers and freight	Switzerland
former East Germany	Freight	Slovenia
former East Germany	Freight	Poland
former East Germany	Freight	Czech Republic
former East Germany	Freight	Hungary

3.10.11 Additional information

We have also supplied population projections and surface areas for each country, broken down into metropolitan, other urban and non-urban regions. The total populations are those used by the SCENES model, using Eurostat Newcronos projections consistent with PRIMES in the future year. Switzerland and Norway do not have populations in the model and the 2020 forecasts have been taken from the "medium growth" forecasts of their official statistics agencies.

The populations have been split using the proportions described in the previous sections, based on cities of size 50 000 etc.

The surface areas of each micro-zone were obtained in a GIS package, and split using population proportions. This will greatly over-estimate the surface area in urban areas because it takes no account of density. Surface areas were only requested very late in the project and no resources were available to tackle the difficult problem of estimating urban areas.

4 The vehicle stock module

4.1 Introduction to the vehicle stock module

The vehicle stock module calculates the vehicle stock in each country every year (1995-2020), by vehicle type, by age and by (emission reduction) technology, depending on the policy environment.

For road and rail transport, the actual stock is modelled. For inland waterways and maritime transport, the amount of vehicle-kilometres is modelled, because a vehicle stock for these modes cannot be allocated to one country. For tram/metro and air transport, emissions are calculated directly form the amount of passenger-km.

For each mode the vehicle stock will be represented on the level of detail needed to apply the fuel consumption and emission calculation methodology detailed in the next section.

4.1.1 Overview of vehicle stock models

In the next table, an overview of vehicle stock models is given.

Table 13: Overview of vehicle stock models in TREMOVE

	vehicle category	*number of vehicle and fuel types*	*vehicle stock model*
Road transport			
	small car	4 vehicle types	vehicles
	big/medium car	9 vehicle types	vehicles
	moped	1 vehicle type	vehicles
	motorcycle	4 vehicle types	vehicles
	light duty vehicle	2 vehicle types	vehicles
	heavy duty vehicle	4 vehicle types	vehicles
	bus	2 vehicle types	vehicles
	coach	1 vehicle type	vehicles
Rail transport			
	metro/tram (*)	2 vehicle types	pkm
	passenger train	5 train types	vehicles
	freight train	4 train types	vehicles
Inland waterways transport			
	inland ship (*)	21 ship types	vkm
Air transport			
	plane (*)	5 aircraft types	pkm

(*) For these transport types, the vehicle stock has not been modelled explicitly.

The next chapters will describe each of these models.

4.1.2 General approach

For road and rail transport, the stock of each vehicle type will be described by generation. If $Stock_i(t,T)$ represents the stock of vehicles of type i in year t and of age T, the 2 basic equations of the module will be :

$Stock_i(t,0) = Sales_i(t)$

where $Sales_i(t)$ = sales of new vehicles of type i in year t

For each transport mode and each year t, the stock of vehicles surviving from the year t-1 will be compared with the desired stock of vehicles needed by transport users in year t. The desired stock will be derived from the transport demands per mode, as calculated in the demand module, and data on annual vehicle usage, occupancy rates and load factors. The difference between desired stock and surviving stock will be equal to the total sales of vehicles for the considered mode in year t.

$Stock_i(t,T) = Stock_i(t\text{-}1,T\text{-}1) – Scrap_i(t,T)$ for $T > 0$

where $Scrap_i(t,T)$ = scrappages of vehicles of type i and age T in year t

The scrappage rates, i.e. the percentage of cars of a certain age that is scrapped, are exogenous and taken from the TRENDS[20] database (except for Austria, Switzerland, Norway and the new Member States). These rates have been derived from analysis of observed time series of vehicle fleet age distributions. In these analyses, it is assumed that vehicle survival probabilities are Weibull distributed.

Within CAFE it is intended to use TREMOVE as a tool to evaluate the effects of policies promoting earlier scrappage of old (and polluting) vehicles. Therefore, the exogenous scrappage rates will be replaced by an endogenous scrappage sub module[21] when needed. This sub module will represent scrappage rates as a function of the technical lifetime of the vehicle, the probability of breakdown before the end of the life, second-hand market prices and policies that directly or indirectly affect vehicle costs such as purchase taxes and scrapping incentives. The endogenous scrappage sub module will be an improved version of the similar sub module that was included in TREMOVE version 1.3a.

Applying these basic equations implies that stock data by age for the base year is needed and that detailed sub modules are needed to estimate vehicle scrappage and vehicle sales.

The general approach is more detailed or more aggregate, depending on the vehicle type. E.g. car modelling is very detailed, air transport rather simplified.

The source for the baseline data (both road and non-road modes) is mostly the data from the TRENDS project.

[20] Samaras S., Zaxariadis Z., Tourlou E., Giannouli M. and Mpampatzimopoulos A. (2002) *Transport and Environment Database System (TRENDS) . Detailed Report 1 : Road Transport Module* Project funded by the European Commission – Directorate General for Transport and Energy

[21] The update to endogenous scrappage rates will be made once the policies to be simulated have been defined in detail.

4.1.3 Note : Flow of second hand cars from EU15 countries to new Member States

Although the issue was investigated, the flow of second hand cars between EU15 countries and new Member States has not been modelled due to lack of data.

TREMOVE initially models the second hand market within a country. TREMOVE models the sales of *new* car – and the scrappage of old cars. The owner of the car is not important – the car could well live as a 2nd, 3rd, 4th hand car during his lifetime, as long as the kilometres are driven within the country.

Within EU15, imports and exports of second hand cars from/to other countries are not considered significant for modelling purposes. Although trade exists, the exchange balance between countries is probably close to zero in Western Europe. But second hand car trade between countries was (at least in the past[22]) important in Eastern Europe. This influences the age distribution of the car stock and therefore the emissions.

The modelling solution is rather tedious as this will require linking all the country models.

4.2 Small car

4.2.1 Methodology

The vehicle stock model for small cars follows the general approach. It consists of a car scrappage sub model and a car sales sub model.

TREMOVE does not include a separate vehicle stock category for leasing cars due to lack of sufficient data.

Second hand cars are not modelled separately. The sale of the car at age 0 is modelled, as well as the scrappage at the end of the lifetime. In the TREMOVE vehicle stock model it does not matter who owns the car during the lifetime.

4.2.2 Vehicle types in the small car stock model

Small cars are cars with an engine size smaller than 1,4 litre.

The following four vehicles types are included in the baseline:

[22] As accession country income per capita will increase in the future, the population will tend to opt more and more for new cars instead of second hand cars.

Table 14: Small car vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type	vehicle technology
small car	gasoline	PCGS small gasoline car -1,4 l	RTG1 - PRE ECE
			RTG2 - ECE 15 00-01
			RTG3 - ECE 15 02
			RTG4 - ECE 15 03
			RTG5 - ECE 15 04
			RTG6 - Improved Conventional
			RTG7 - Open Loop
			RTG8 - Euro I - 91 441 EEC
			RTG9 - Euro II - 94 12 EC
			RTG10 - Euro III - 98 69 EC Stage20
			RTG11 - Euro IV - 98 69 EC Stage200
		PCGHS small hybrid gasoline car -1,4 l	RTG10 - Euro III - 98 69 EC Stage20
			RTG11 - Euro IV - 98 69 EC Stage200
	diesel	PCDS small diesel car -1,4 l	RTD4 - Diesel/LPG Euro III - 98 69 EC Stage20
			RTD5 - Diesel/LPG Euro IV - 98 69 EC Stage200
		PCDHS small hybrid diesel car -1,4 l	RTD5 - Diesel/LPG Euro IV - 98 69 EC Stage200

Table 15: Availability of small car types per country

	small gasoline car	small hybrid gasoline car	small diesel car	small hybrid diesel car
AT	x	x	x	x
BE	x	x	x	x
CH	x	x	x	x
CZ	x	x	x	x
DE	x	x	x	x
DK	x	x	x	x
ES	x	x	x	x
FI	x	x	x	x
FR	x	x	x	x
GR	x	x		
HU	x	x	x	x
IE	x	x	x	x
IT	x	x	x	x
LU	x	x	x	x
NL	x	x	x	x
NO	x	x	x	x
PL	x	x	x	x
PT	x	x	x	x
SE	x	x	x	x
SI	x	x	x	x
UK	x	x	x	x

The age classes 1 to 55 are included in the model. In 1995 all vehicles are between 0 and 20 years (i.e. earliest vintage is 1965[23]); in 2020 all vehicles are between 0 and 55 years. This way one can still derive the exact technology distribution for 55-year-old cars in 2020.

23 This is an important improvement compared to TREMOVE 1.3a.

The car purchase model estimates the number of new cars sold per vehicle type. The vehicle technologies (Euro-classes) are derived form the age structure, e.g. every car sold between 1997 and 1999 is supposed to be a Euro II car, between 2000 and 2005 a Euro III car.

4.2.3 Car scrappage sub module

Scrapping is a function of the technical lifetime of the vehicle, the probability of breakdown before the end of the planned technical life and policies that directly or indirectly affect car costs such as purchase taxes and scrapping incentives. Scrappage is partly endogenous, partly exogenous to the model.

The *endogenous scrapping* is based on the idea that there is an age dependent probability of breakdown. Following breakdown, repair expenditures are needed to restore vehicles to operating conditions. The required repair expenditures are assumed to follow a normal distribution. This assumes that vehicles are homogeneous, i.e. that, after repair, a repaired vehicle cannot be distinguished from other vehicles of the same generation. Non-repaired vehicles cannot be used and have a market value of zero.

The *exogenous scrapping* rate represents cars that can no longer be repaired.

In TREMOVE, only the endogenous scrappage has been modelled.

This scrapping rate is, for a vehicle of type i and age T, calculated as:

$$Exscrap_i(T) \quad = \quad 1 - [PP_i(T) / PP_i(T\text{-}1)]$$

Where

$PP_i(T)$: Survival probability of a vehicle of type i and age T, i.e. the share of vehicles that remain operating T years after being sold[24].

The scrappage rates, reflect the TRENDS scrappage rates in baseline, unless country specific data was available (this was the case for Switzerland and Austria). Note that in TRENDS equal scrappage rates for all cars, all commercial vehicles, and all buses are used. It is expected that within the framework of the COST 346 action, more national estimates on scrappage rates will become available during the coming years.

4.2.4 Deriving the total number of vehicles from passenger-km

For each year t, the stock of small cars surviving from the year t-1 is compared with the desired stock of small cars needed by transport users in year t. The desired stock is derived from the transport demands, as calculated in the demand module, and data on annual vehicle usage, occupancy rates and load factors. The difference between desired stock and surviving stock is set equal to the total sales of small cars in year t.

The transport demand module delivers passenger-km. They are converted into vehicle-km using occupancy rates, consistent with the SCENES model. The number of vehicle-km for small car directly comes out of the transport demand module.

[24] This is assumed to be related to the age and technical life time.

The total number of vehicle-km in TREMOVE will be divided with the mileage per car (the number of km a vehicle drives during a year) to get the desired number of cars in a year.

Since we know the latter (number of cars) from the TRENDS baseline, we can easily derive the mileage per car in a baseline. The TRENDS database also delivers an estimated of mileage of per car, but the absolute number is not used, since consistency with the transport demand figures is needed. They are used though for diversification of mileage figures between vehicle types and ages.

Mileage is modelled exogenous (kept constant by policy simulation, e.g. if medium cars are replaced by big cars, the average mileage of big cars declines, so that the weighted average mileage over medium and big cars does not change). This is realistic for private transport, as consumers that switch from medium to big cars will not drive more kilometres per year with these.

This also means that, in the model, the weighted average of (diesel + gasoline) annual car mileage remains constant in the future. In the extreme case that stock would evolve to 100% diesel cars, diesel car mileage will go down to the average 1995 car (gasoline + diesel) level.

4.2.5 The car choice model

Once known how many new cars will be bought in a certain year, the question is which car. Because different car types and technologies exist, a model has been developed to split total sales of small cars into sales per fuel type.

It has to be noted that we model the choice conditional upon purchase. We do not model the choice to purchase a car or not, only the market shares of the different cars on the market.

More than in other modes, the choice of a car is not only a question of prices. E.g. the recent increase in diesel shares was not due to the fact that diesels are cheaper (they have been cheaper than gasoline for a long time now), but due to the fact that these cheaper cars now are as advanced as gasoline cars in terms of acceleration, top speed etc.

For this, a behaviour function (multinomial logit model) was developed, relating consumers and firms' small car purchase decisions to costs and characteristics of the different fuel types. The behaviour function is based on discrete choice theory.

4.2.6 Discrete choice theory

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[25], Train[26], Anderson[27] and Train[28].

25 Ben-Akiva, M.; Lerman, S.R. (1985) Discrete Choice Analysis: Theory and Application to Travel Demand, London
26 Train, K. (1990) Qualitative Choice Analysis, London
27 Anderson, S.P.; de Palma, A.; Thisse, J.-F. (1992) Discrete Choice Theory of Product Differentiation, London
28 Train, K.E. (2003) Discrete Choice Methods with Simulation, Berkeley

4.2.6.1 Consumer behaviour

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).

$U_{nj} = V_{nj} + e_{nj}$
where:
V_{nj}: the deterministic part of the utility
e_{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 e_{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 e_{nj}, different models are distinguished.
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 ? j.

4.2.6.2 Discrete choice models

In this paragraph, a small overview of the most common discrete choice models will be provided, focussing on the (dis)advantages for the design of a vehicle technology choice model for TREMOVE.

Multinomial logit (MNL)

The multinomial logit model has been applied widely for all kind of logit choice modelling exercises in consumer theory. It is based on the assumption that the random utility terms have a double exponential or Gumbel distribution.

The MNL has however some important disadvantages. Since the error terms are supposed to be i.i.d., the alternatives have to fulfil the IIA property, which is unlikely to happen for private cars: e.g. medium diesel and gasoline cars (for size classification: see Table 18) may be much closer substitutes to each other than to big cars.

The major advantage of the MNL model is the existence of closed form expressions for the chances that the different alternatives are chosen, and hence for their market shares. This allows for efficient model estimation.

Nested Multinomial logit (NMNL)

The nested multinomial logit allows for data not fulfilling the IIA property: some correlation in preferences can be modelled by structuring the choice alternatives in nests. The model keeps the advantage of the closed form expression for choice probabilities.

Mixed logit (ML)

The mixed logit model is considered to be the most promising state of the art discrete choice model currently available.

The ML model doesn't suffer from most problems of the (N)MNL: the data doesn't need to comply with IIA, it can handle many forms of correlation in choices (e.g. induced by repeated choices) in a proper way, etc. However, ML does introduce a new problem: there's no closed form to calculate choice probabilities.

Mixed logit models have been estimated during the last decade. However, although the theory is rather clear, estimation and data issues are far from clear. The absence of a closed form may require much work to implement it in a model.

Multinomial Probit (MP)

The multinomial probit model is based on the assumption that the random utility term is distributed jointly normal. As for the ML, the MP doesn't suffer from the limiting IIA property nor does it object repeated choice situations. Moreover, any pattern of correlation in the unobserved factors can be implemented in this model.

But as for the ML model, there's no closed expression for the choice probabilities. Another restriction is the reliance on the normal distribution, which doesn't hold in all situations.

4.2.7 Literature on car purchase models

For the modelling of market shares of conventional technologies, past studies rely on existing data (revealed preference). Extensive databases providing data on car sales, which can be used to estimate a choice model.
Main drawback of this method is the important correlation between different variables in revealed preference data. This creates a host of difficulties when estimating the choice model. However, revealed preference data represent real-world behaviour, which is a major advantage over stated preference data.
We limit this overview to the models simulating (part of) the European car market. For each study, we discuss the model specification, the database used for estimation of the model (time period covered, geographic coverage) and the resulting model coefficients.

4.2.7.1.1 Verboven 1996

Verboven (1996)[29] estimates a nested logit model for private car vehicle type choice for France, Germany, United Kingdom and Belgium, based on revealed preference data (vehicle sales). The database set was collected by the author and included sales for most car models (512 observations) for 1990. The model was used in a larger model implemented to research international price discrimination in the European car market.
Four technical characteristics as well as country of origin were included as attributes. The technical characteristics that enter the utility formula in a logarithmic are horsepower, weight, width and height, of which for the last two no significance was found. Several nesting structures were tested for, but most were rejected. The only specification to remain unrejected specified groups to correspond to a marketing based classification and subgroups to country of origin (domestic or foreign).

4.2.7.1.2 Verboven 2002

Verboven (2002)[30] estimates a simple logit model as well as two nested logit models for private car choice in five European markets during 1970-1999. The data set used for estimation covers sales of (nearly) all cars sold in Belgium, France, Germany, Italy and the UK, which results in a total number of 13.000 observations.
The author selects horsepower, fuel inefficiency, width, height, purchase price and a dummy for foreign as car variables in the model.
The simple logit specification resulted in some parameters having an unexpected sign (e.g. a negative horsepower coefficient). For the nested logit specifications, all estimated coefficients have the expected sign. The nesting structure is the same as in Verboven (1996), the difference between the two nested models estimated is in the specification of the coefficient of the inclusive value. For one model, these coefficients were constrained to be the same for all segments and subsegments, whereas for the other model a more flexible specification was estimated, allowing the parameters to vary by (sub)segment.

4.2.7.1.3 De Jong 1996

De Jong (1996)[31] estimates a multinomial logit model for vehicle technology choice as part of a larger model integrating vehicle holding duration, type choice and use. Revealed preference data were used to estimate several nesting structures, of which only one was found to result in acceptable tree coefficients: with separate nests for diesel and non-diesel cars.
Two models were estimated, based on two datasets, one including only make/model combinations and the other covering make/model/age-of-car combinations. The attributes included cover income and cost variables, dummies related to the difference between the previous and the new car and attributes of the vehicle.
The datasets used for estimation covered The Netherlands and were collected by a questionnaire in 1992.

[29] Verboven, F. (1996) International price discrimination in the European car market, RAND Journal of Economics, Vol. 27, No. 2, pp. 240-268.
[30] Verboven (2002) Quantitative Study to Define the Relevant Market in the Passenger Car Sector, Final Report (Downloadable from website http://europa.eu.int/comm/competition/car_sector/distribution/eval_reg_1475_95/studies/study01.pdf).
[31] De Jong, G. (1996) A disaggregate model system of vehicle holding duration, type choice and use, Transportation Research B, Vol. 30, No. 4, pp. 263-276.

4.2.7.1.4 COWI 2002

A study by COWI (2002)[32] on fiscal measures to reduce CO_2 emissions from new passenger cars includes a car choice model. This model consists of two sub models, one for the private car market and another to calculate the demand for company cars, and was estimated based on a Danish dataset. The private car model is estimated for 24 types of car users, depending on the car buyer's family type and income class.

The variables that were included:

- Price of the car (inclusive tax and VAT)
- Running cost (fuel and circulation tax)
- Size of the car (length)
- Luggage capacity
- Acceleration

The company car model has six "agents", depending on sector and whether the company manager or the employee decides which car to buy. The variables included in the model are:

- Cost of acquisition (personal taxation rules)
- Running cost (personal taxation rules)
- Size of the car (length)
- Luggage capacity
- Acceleration
- Horse Power

The private/company split is modelled by a binary discrete choice model.

4.2.7.1.5 Conclusion and application to TREMOVE

The models that have been designed in past studies were estimated on extensive datasets carrying disaggregate sales data for a limited number of countries and in most cases also covering a limited time period.

Most models include car variables covering:

- performance: power, weight or acceleration;
- cost: purchase cost and fuel cost;
- size: dimension of the car, including luggage space.

Both nested logit and simple multinomial logit modelling frameworks have been applied. The nested logit specification seems to be more appropriate, with nests based on marketing classifications or fuels.

For TREMOVE, we decided not to implement a literature based model, considering:

- In TREMOVE, we want to forecast market shares based on aggregate car data rather than disaggregate, a model estimated making use of a dataset covering aggregate sales data can overcome this problem.

[32] COWI (2002) Fiscal Measures to Reduce CO2 Emissions from New Passenger Cars, Final Report (Downloadable from website http://europa.eu.int/comm/environment/co2/cowi_finalreport.pdf).

- Although the marketing based classification will probably allow a more realistic classification for modelling car purchase, we do not include this classification in TREMOVE mainly since it does not relate to classification in common EU emission calculation models; as such we cannot use such a classification as a base for nested logit model specification.
- The specification of the conventional car choice model proposed here (and in the paragraphs beyond) does not differ fundamentally from what has been applied in TREMOVE 1.3a[33]. Special attention has been paid to the car sales dataset used for the estimation of the model coefficients.

We decided to include the following car parameters:

- Acceleration
- Lifetime Cost

We also included the level of income of the car buyer.

The construction of a dataset for model estimation, including values for these parameters as well as the number of cars sold is discussed beyond.

As discussed earlier, we need two (independent) choice models: one for medium and big cars (see §4.3.5 and a second for small cars (see §4.2.8).

4.2.8 Model estimation

4.2.8.1 Structure of the model

To estimate the model we need revealed preference sales data. However, this data is not available for all vehicle types we want to include in the model (see Table 14). More specifically, we do not have any data regarding hybrid technologies as these do not exist so far or have been introduced only very recently on a rather limited scale. In the small engine size, the observations regarding conventional diesel cars are very limited as we have seen a full market introduction of this technology category only very recently.

For small cars, the choice between gasoline and diesel was impossible to estimate on existing revealed preference data, as up to 2002 only one technology (gasoline) was available in this size class. The model then was estimated base upon the medium/big car choice model (see §4.3.5).

The data used for estimation were based on statistics provided by COWI[34]. Aggregated quarterly data were used:

- vehicle purchase cost (in €$_{2000}$);
- registration taxes (in €$_{2000}$);
- ownership taxes (in €$_{2000}$);
- fuel efficiency (in l/km);
- fuel cost[35] (in €$_{2000}$/l);
- acceleration (in s from 0 to 100 km/h).

[33] European Commission, Standard & Poors' DRI, K.U.Leuven. *The AOP II Cost – Effectiveness Study.* August 1999.
[34] http://www.cowi.dk
[35] IEA (2003) Energy prices & taxes - quarterly statistics - first quarter, Paris.

The cost factors (including fuel efficiency) enter the model through the lifetime cost, which is calculated as described in §4.2.9.3.

The coefficients for the model after the dummies are introduced are given in Table 16 and Table 17. Note that the relative lifetime cost coefficient has been estimated making use of quarterly data, therefore a factor 4 has to be added in the final model where annual GDP projections will be used.

For the inclusive value coefficient for small cars, we assume a value of 0,1 (which is in line with the values used for medium and big, see §4.3.5 Note that this coefficient is a general scaling factor rather than a real nesting coefficient, as this model is limited to the small size category only.

We assume a diesel dummy of -0,1 for all countries in order to get realistic diesel shares compared to 2002 observation figures. The medium/big model has country specific dummies (see §4.3.5)

Table 16: Coefficients of generic parameters and inclusive value (small cars)

parameter	unit	coefficient
lifetime cost / quarterly GDP per inhabitant	LFC in €2000/km; GDP per inhabitant in 10.000 €95	-0,4585391
acceleration	s from 0 to 100 km/h	-0,045565
inclusive value small		0,1100573

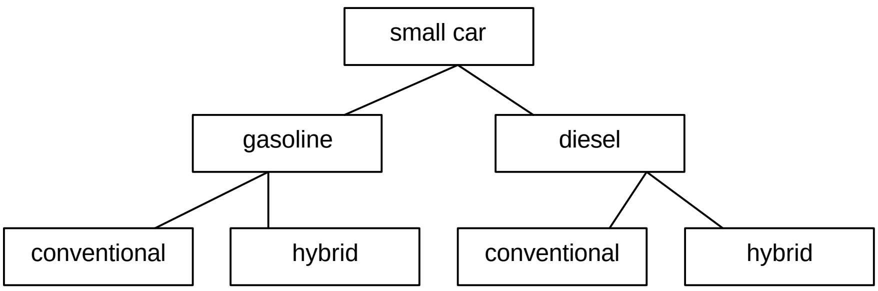
Table 17: Coefficients of dummies for diesel cars (small cars)

country	coefficient
All countries	-0,1

4.2.8.2 Hybrids

As discussed before, the model used for estimation (see Figure 12) is further extended in order to allow for the simulation of hybrid technologies' shares (see Table 14). For each conventional technology we introduce an hybrid equivalent. This is done by adding a new level to the nested structure.

Figure 12: Structure of nested logit model for small cars



The inclusive value coefficient has been assumed to be 0,2. This means that the probabilities of the conditional choice between hybrid or conventional make of a given technology are rather sensitive to the differences between both makes. Sensitivity analysis has shown that the value of 0,2 does lead to acceptable results.

The properties of hybrid technologies introduced in TREMOVE are based on a parallel (or combined) hybrid assumption both for diesel and gasoline cars, and for all size classes.

Baseline data for hybrid technologies are based on Verbeiren et al. 2003:

- purchase cost: an additional cost of € 5190 in 2000, € 5000 in 2010 and about € 3250 in 2020;
- fuel efficiency: a reduction of 20% for diesel and about 30% for gasoline

VUB-etec and ULB-ceese (2001) [36] assume repair and maintenance costs to be equal to the reference vehicle, but do not motivate this assumption.

In TREMOVE we assume that the same repair and maintenance factor apply for the equivalent hybrid and conventional technologies, which means a somewhat higher R&M cost for hybrids (proportional to purchase cost increase).
For the other variables (taxes, insurance as well as e.g. performance) we assume them defined the same way as for the reference conventional technology.

4.2.8.3 Greece

Greece has been excluded from the model estimation because of the different choice Greeks face upon vehicle purchase: diesel technologies are not available for private car use (except taxis).
In the TREMOVE, the diesel share for Greece has been taken fixed exogenously and kept constant over the modelling period.

4.2.8.4 Formulas and the coefficients used (small cars)

The formulas are:

$$Share_{PCGS}=\frac{e^{\frac{V_{PCGS}}{\tau_1\cdot\tau_{small}}}}{e^{IV_{GSLS}}}\cdot\frac{e^{\tau_1\cdot IV_{GSLS}}}{e^{\tau_1\cdot IV_{GSLS}}+e^{\tau_1\cdot IV_{DSLS}}}$$

$$Share_{PCGHS}=\frac{e^{\frac{V_{PCGHS}}{\tau_1\cdot\tau_{small}}}}{e^{IV_{GSLS}}}\cdot\frac{e^{\tau_1\cdot IV_{GSLS}}}{e^{\tau_1\cdot IV_{GSLS}}+e^{\tau_1\cdot IV_{DSLS}}}$$

$$Share_{PCDS}=\frac{e^{\frac{V_{PCDS}}{\tau_1\cdot\tau_{small}}}}{e^{IV_{DSLS}}}\cdot\frac{e^{\tau_1\cdot IV_{DSLS}}}{e^{\tau_1\cdot IV_{GSLS}}+e^{\tau_1\cdot IV_{DSLS}}}$$

$$Share_{PCDHS}=\frac{e^{\frac{V_{PCDHS}}{\tau_1\cdot\tau_{small}}}}{e^{IV_{DSLS}}}\cdot\frac{e^{\tau_1\cdot IV_{DSLS}}}{e^{\tau_1\cdot IV_{GSLS}}+e^{\tau_1\cdot IV_{DSLS}}}$$

with

$$IV_{GSLS}=\ln\left(e^{\frac{V_{PCGS}}{\tau_1\cdot\tau_{small}}}+e^{\frac{V_{PCGHS}}{\tau_1\cdot\tau_{small}}}\right)$$

$$IV_{DSLS}=\ln\left(e^{\frac{V_{PCDS}}{\tau_1\cdot\tau_{small}}}+e^{\frac{V_{PCDHS}}{\tau_1\cdot\tau_{small}}}\right)$$

and

$$V_{PCGS}=\beta_{acceleration}\cdot acceleration_{PCGS}+\beta_{LFC}\cdot\frac{LFC_{PCGS}}{GDPperINH}$$

$$V_{PCGHS}=\beta_{acceleration}\cdot acceleration_{PCGHS}+\beta_{LFC}\cdot\frac{LFC_{PCGHS}}{GDPperINH}$$

[36] VUB-etec, ULB-ceese (2001) Schone voertuigen - Verslag WP1 - "Definitie van het begrip Schone Voertuigen", Brussel.

$$V_{PCDS} = \beta_{acceleration} \cdot acceleration_{PCDS} + \beta_{LFC} \cdot \frac{LFC_{PCDS}}{GDPperINH} + dum_{SDSL}$$

$$V_{PCDHS} = \beta_{acceleration} \cdot acceleration_{PCDHS} + \beta_{LFC} \cdot \frac{LFC_{PCDHS}}{GDPperINH} + dum_{SDSL}$$

The variables are:

- acceleration: acceleration time from 0 to 100 km/h
- LFC: lifetime cost in $€_{2000}$ per km
- GDPperINH: GDP per inhabitant in $€_{1995}$

The values of the coefficients are:

- $ß_{acceleration}$ = -0,045565
- $ß_{LFC}$ = -0,4585391*40000
- t_1 = 0,2
- t_{small} = 0,1
- dum_{SDSL} = -0,1

4.2.9 Base data

4.2.9.1 Stock data for 1995

For the car stock, the TRENDS data (TRansport and ENvironment Database System) has been used for the base year. TRENDS (version 1) has been finalised in October 2002. In principle TRENDS comprises the data needed for the base year (1995) for road and for the EU15 countries as it is required for TREMOVE, but not for additional countries.

The road transport module developed in the framework of the TRENDS project produces both analytical and aggregated results for the EU15 countries and for a time-span of 50 years (1970-2020). More specifically, the road transport module calculates various transport-related parameters, such as the annual mileage, vehicle population, average age, vehicle emissions and fuel balance, for all vehicle categories considered by COPERT. Additionally, temporal and spatial disaggregation of the estimated vehicle emissions was conducted for the base year 1995.

The main input from TRENDS to TREMOVE is a base year description (1995) of the vehicles by category (and type). This description includes the number of vehicles as well as their age distribution, which allows inferring the appropriate (emission reduction) technologies. While the number of vehicles is based on statistical data, the age distribution is a result of the TRENDS road module. This module also includes activity data (mileage), but since TREMOVE integrates the demand from other projects (i.e. SCENES), only the number of the vehicles including age distribution has been taken from TRENDS.

Road vehicle stock data for Norway and Switzerland has been derived from national and EUROSTAT statistics. Accession country data for the passenger car fleet was available from EUROSTAT[37] and/or national sources for all 4 countries for the years (1980/85/89 and up to 1998). In addition, in the

[37] Source: EUROSTAT / EEA data collection, file “AC-LFT-PC (vehicle fleet Eurostat).xls”

context of waste, EEA produced estimates about end of life-vehicles based on a comparable vehicle turnover model, which includes also first estimates about lifetime functions[38].

Note that for the new Member States (CZ, HU, PL, SI), we did not use 1995 but 2000, 2002, 2003 as "base year" for the fleet data.

4.2.9.2 Sales data for the forecast years 1996-2002

Sales numbers are taken from the database that has been provided by DG ENV and that was constructed under the fuel-efficiency agreements between the Commission and the car manufacturers (so-called ACEA-agreement). The most recent version of this database covers the time period 2000-2002. This database report the composition of new car sales.

The logit models are calibrated such that the market shares of cars in 2000-2002 are similar to those in the ACEA reports. Thus new car sales are consistent with this database, and consequently there are no large discrepancies between the TREMOVE (all ages) fleet distribution and the actual fleets.

4.2.9.3 Cost data

Cost data have been based mainly on what has been provided by COWI. Quarterly data were available for all EU15 countries (plus Norway and Switzerland) for 1999 and 2000 (last quarter is missing for some countries and only partially covered for others).

To calculate the lifetime cost, we assumed an expected lifetime of 12,5 years for all countries. We averaged the mileages over the different car categories, as expected mileage is an attribute of the car buyer rather than the car, and hence should not differ between the cars in order to represent car choice as realistic as possible. This allowed us to calculate the lifetime cost, assuming an interest rate of 4% annually.

The different cost components that enter the lifetime cost are detailed beyond. All cost figures are expressed in $euro_{2000}$. The formula used for lifetime cost calculations is:

$$LFC = C_{annualtax} + C_{r\&m} + C_{fuel} + C_{insurance} + C_{purchase+registration} \cdot \frac{1,04^{12,5} \cdot 0,04}{\left(1,04^{12,5} - 1\right)}$$

Where:

- $C_{purchase+registration}$ = purchase cost (VAT included) and registration tax;
- $C_{annualtax}$ = annual taxes, see §4.2.9.7;
- $C_{r\&m}$ = expected average annual repair and maintenance costs (VAT included);
- C_{fuel} = expected annual fuel costs (excise taxes and VAT included);
- $C_{insurance}$ = expected annual insurance costs (VAT included).

As new technologies become more and more available and cheaper, this will make the logit model change over time.

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[38] TERM 2002 11a AC - Waste from road vehicles (elv) [final draft July 2002].doc. The methodology has been described in EEA Technical report No 28, *Baseline projections of selected waste streams – development of a methodology*; the application is described in EEA-ETC/WMF, 2001. Scrapping of passenger cars in 16 accession countries to the European Union until 2015. Assessment/scenario made by the European Topic Centre on Waste and Material Flows of the European Environment Agency (EEA-ETC/WMF). Risoe National Laboratory (Kilde, Niels & Helge A. Larsen). Denmark, December 2001.

To determine the purchase cost of ***small diesel cars***, we collected a small purchase cost dataset comparing small diesel cars to their gasoline equivalent. The data has been based on the Technicar database by Febiac[39] in August 2004. The resulting average difference in purchase cost between a small diesel and gasoline car was 1278 euro (in 2000).

For repair and maintenance costs, we assume the same factor for small gasoline cars to apply to small diesel cars. We assume small diesel cars to be introduced from 2002 on.

4.2.9.4 Insurance cost

Insurance cost is provided by COWI as a percentage of purchase cost (excluding VAT and registration taxes). We applied this percentage to the purchase cost baseline.

4.2.9.5 Purchase cost

Purchase cost (including registration taxes and VAT) are taken from the data provided by COWI for 2000.
The baseline for the time period beyond 2000 is designed by applying the index provided by COWI to the year 2000 data. This includes the assumptions that registration taxes evolve proportionally to purchase cost.

4.2.9.6 Repair and maintenance cost

COWI studied the concept for calculation of repair and maintenance costs that was applied in TREMOVE 1.3a. They concluded that the resulting figures are realistic but suggested to include a country-specific coefficient that reflects differences in labour costs.

4.2.9.7 Annual taxes

Annual taxes for 2000 are provided by COWI. These taxes are assumed to be kept constant in the baseline. One should note that this is not in line with registration taxes, which are assumed to evolve in line with car purchase cost.

4.2.9.8 Fuel costs

Fuel costs are calculated based on fuel prices, expected annual mileages, and fuel efficiency.

All fuel prices (and future evolution) have been made consistent with PRIMES, albeit that we included 2001, 2002 and 2003 prices from statistics when available, whereas PRIMES did not (they use forecasts from 2000 onwards). Note that given 9/11 effects etc. differences PRIMES versus TREMOVE for 2001-2003 are significant.

4.2.9.9 Acceleration

The “power” of the car has been modelled by the proxy acceleration.

[39] http://www.febiac.be

Baseline evolution for acceleration has been based on the sales data provided by COWI. For 1999 and 2000 we have statistical data available for all car classes.
The growth rate before 1999 and after 2000 has been based on EU average annual growth in 1999 and 2000, and applied up to 2005[40].

For small diesel cars, EU15-average figures have been used for 2000.

For the central European countries, no observations were available. Therefore, EU15 average figures have been assumed to apply to these countries.

4.2.10 Policy simulations

During policy simulations, new technologies can be added to the model. As for new technologies, no historical data can be used to calibrate the models. Therefore, literature survey and a stated preference survey that was conducted in Belgium will be used to construct an additional choice model that chooses between conventional and new technologies and within the new technologies, the type of the technology.

4.3 Big/medium car

4.3.1 Methodology

The vehicle stock model for big/medium cars follows the general approach. It consists of a car scrappage sub model and a car sales sub model.

4.3.2 Vehicle types in the big/medium car stock model

Big/medium cars are cars with an engine size larger than 1,4 litre. Big cars are larger than 2,0 litre.

The following 9 vehicles types are included in the baseline:

Table 18: Medium/big vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type	vehicle technology
medium/big car	gasoline	PCGM medium gasoline car 1,4-2,0 l	RTG1 - PRE ECE
			RTG2 - ECE 15 00-01
			RTG3 - ECE 15 02
			RTG4 - ECE 15 03
			RTG5 - ECE 15 04
			RTG6 - Improved Conventional
			RTG7 - Open Loop
			RTG8 - Euro I - 91 441 EEC
			RTG9 - Euro II - 94 12 EC
			RTG10 - Euro III - 98 69 EC Stage20
			RTG11 - Euro IV - 98 69 EC Stage200
		PCGHM med. hybrid gasoline car 1,4-2,0 l	RTG10 - Euro III - 98 69 EC Stage20
			RTG11 - Euro IV - 98 69 EC Stage200

40 The EU average value for the big diesel category is rather high for the 1999-2000 period, therefore we assume a lower value that is closer to medium diesel cars acceleration.

vehicle category	fuel type	vehicle type	vehicle technology
		PCGB big gasoline car +2,0 l	RTG1 - PRE ECE
			RTG2 - ECE 15 00-01
			RTG3 - ECE 15 02
			RTG4 - ECE 15 03
			RTG5 - ECE 15 04
			RTG8 - Euro I - 91 441 EEC
			RTG9 - Euro II - 94 12 EC
			RTG10 - Euro III - 98 69 EC Stage20
			RTG11 - Euro IV - 98 69 EC Stage200
		PCGHB big hybrid gasoline car +2,0 l	RTG10 - Euro III - 98 69 EC Stage20
			RTG11 - Euro IV - 98 69 EC Stage200
	diesel	PCDB big diesel car +2,0 l	RTD1 - Diesel/LPG Conventional
			RTD2 - Diesel/LPG Euro I - 91 441 EEC
			RTD3 - Diesel/LPG Euro II - 94 12 EC
			RTD4 - Diesel/LPG Euro III - 98 69 EC Stage20
			RTD5 - Diesel/LPG Euro IV - 98 69 EC Stage200
		PCDHB big hybrid diesel car +2,0 l	RTD5 - Diesel/LPG Euro IV - 98 69 EC Stage200
		PCDHM med. hybrid diesel car 1,4-2,0 l	RTD5 - Diesel/LPG Euro IV - 98 69 EC Stage200
		PCDM medium diesel car 1,4-2,0 l	RTD1 - Diesel/LPG Conventional
			RTD2 - Diesel/LPG Euro I - 91 441 EEC
			RTD3 - Diesel/LPG Euro II - 94 12 EC
			RTD4 - Diesel/LPG Euro III - 98 69 EC Stage20
			RTD5 - Diesel/LPG Euro IV - 98 69 EC Stage200
	LPG	PCL medium+big LPG car +1,4 l	RTD1 - Diesel/LPG Conventional
			RTD2 - Diesel/LPG Euro I - 91 441 EEC
			RTD3 - Diesel/LPG Euro II - 94 12 EC
			RTD4 - Diesel/LPG Euro III - 98 69 EC Stage20
			RTD5 - Diesel/LPG Euro IV - 98 69 EC Stage200

The age classes 1 to 55 are included in the model. In 1995 all vehicles are between 0 and 20 years (i.e. earliest vintage is 1965[41]); in 2020 all vehicles are between 0 and 55 years. This way one can still derive the exact technology distribution for 55-year-old cars in 2020.

The car purchase model estimates the number of new cars sold per vehicle type. The vehicle technologies (Euro-classes) are derived form the age structure, e.g. every car sold between 1997 and 1999 is supposed to be a Euro II car, between 2000 and 2005 a Euro III car.

Table 19: Availability of medium/big car types per country

	medium gas. car	med. hybrid gas. car	big gas. car	big hybrid gas. car	med. diesel car	med. hybrid diesel car	big diesel car	big hybrid diesel car	medium+big LPG car
AT	x	x	x	x	x	x	x	x	
BE	x	x	x	x	x	x	x	x	x
CH	x	x	x	x	x	x	x	x	
CZ	x	x	x	x	x	x	x	x	x
DE	x	x	x	x	x	x	x	x	
DK	x	x	x	x	x	x	x	x	x
ES	x	x	x	x	x	x	x	x	x
FI	x	x	x	x	x	x	x	x	
FR	x	x	x	x	x	x	x	x	

41 This is an important improvement compared to TREMOVE 1.3a.

	medium gas. car	med. hybrid gas. car	big gas. car	big hybrid gas. car	med. diesel car	med. hybrid diesel car	big diesel car	big hybrid diesel car	medium+big LPG car
GR	x	x	x	x	x		x		x
HU	x	x	x	x	x	x	x	x	x
IE	x	x	x	x	x	x	x	x	
IT	x	x	x	x	x	x	x	x	x
LU	x	x	x	x	x	x	x	x	x
NL	x	x	x	x	x	x	x	x	x
NO	x	x	x	x	x	x	x	x	
PL	x	x	x	x	x	x	x	x	x
PT	x	x	x	x	x	x	x	x	
SE	x	x	x	x	x	x	x	x	
SI	x	x	x	x	x	x	x	x	x
UK	x	x	x	x	x	x	x	x	

4.3.3 Car scrappage sub module

The model is equal to the one for small cars. See §4.2.3.

4.3.4 Deriving the total number of vehicles from passenger-km

Again, the model is equal to the one for small cars. See §4.2.4.

4.3.5 The car choice model

4.3.5.1 Structure of the model

To estimate the model we need revealed preference sales data. As for small cars, this data is not available for all medium and big vehicle types we want to include in the model (see Table 18). More specifically, we do not have any data regarding hybrid technologies as these do not exist so far or have been introduced only very recently on a rather limited scale.

The model for medium and big technologies is estimated making use of existing revealed preference data.

The data used for estimation were based on statistics provided by COWI[42] for lifetime costs and acceleration. Aggregated quarterly data were used:

- vehicle purchase cost (in $€_{2000}$);
- registration taxes (in $€_{2000}$);
- ownership taxes (in $€_{2000}$);
- fuel efficiency (in l/km);
- fuel cost[43] (in $€_{2000}$/l);
- acceleration (in s from 0 to 100 km/h).

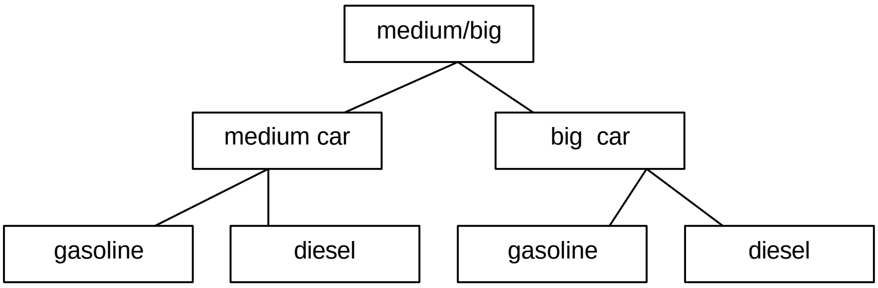
The cost factors (including fuel efficiency) enter the model through the lifetime cost.

[42] http://www.cowi.dk
[43] IEA (2003) Energy prices & taxes - quarterly statistics - first quarter, Paris.

We also added GDP per inhabitant (in constant prices) as a proxy for household income. This variable is used in the model to explain difference in the share of big versus medium cars across countries as well as evolutions in time. The baseline evolution for GDP per inhabitant has been taken from Newcronos up to 2005 (statistics & forecasts: table a_gdp_k) [44]. Beyond 2005, annual growth rates have been taken from the PRIMES model[45]. Quarterly data were available for most countries for the entire time period. For the missing countries we filled in the data by using annual GDP-figures, or dividing overall GDP figures (quarterly) by population statistics (annually). For the UK the 2000 quarters were missing, this was solved by applying the evolution in total GDP (quarterly) to the figure for GDP per inhabitant available for the 4th quarter of 1999 (hence assuming a constant population).

The model is specified as nested logit, where diesel and gasoline are in the same nest for medium as well as big engine size classes.

Figure 13: Structure of nested logit model used for estimation medium/big cars



At a first stage we estimated a model without country specific dummies. The estimation results are in Table 20. The model has been estimated using actual sales numbers as frequency weight for the observations.

Table 20: Coefficients of model without dummies

parameter	unit	coefficient
lifetime cost / GDP per inhabitant	LFC in €2000/km; GDP per inhabitant in 10.000 €95	-0,671
acceleration	s from 0 to 100 km/h	-0,0272
big	dummy	-2,39
income * big	'€95	0,000151
inclusive value medium		0,0832
inclusive value big		0,325

Note that the lifetime cost enters the model combined with GDP per inhabitant. This results in a more realistic model behaviour. A similar relative cost variable has been used by e.g. Brownstone and Train[46].

When we simulate technology shares and compare them to observations, the difference for the medium-big shares are generally within 10% point. Only for Denmark and Norway we observe difference between modelled and observed shares for medium versus big of about 15% point.

[44] http://europa.eu.int/newcronos

[45] Mantzos, L., Capros, P., Kouvaritakis, N., Zeka-Paschou, M. (2003) European energy and transport trends to 2030, Luxembourg

[46] Brownstone, D., Train, K. (1999) Forecasting new product penetration with flexible substitution patterns, Journal of Econometrics, 89, pp. 109-129

The differences between observations and simulation are however larger for diesel versus gasoline. Here we find difference of more than 20 % point for more than half of the observations. This is unacceptable.

In order to better capture differences in purchase behaviour between countries, country-specific dummies for diesel-cars are introduced in the model. The introduction of dummies is expected to result in a better fit for the diesel-gasoline shares (forecast to observation). Also, the forecast of shares medium-big may further increase.

The coefficients for the model after the dummies are introduced are given in Table 21 and Table 22. Note that the relative lifetime cost coefficient has been estimated making use of quarterly data, therefore a factor 4 has to be added in the final model where annual GDP projections will be used. Similarly, the coefficient for income * big has to be divided by four when annual GDP data is used.

Table 21: Coefficients of generic parameters and inclusive value

parameter	unit	coefficient
lifetime cost / quarterly GDP per inhabitant	LFC in €2000/km; GDP per inhabitant in 10.000 €95	-0,4585391
acceleration	s from 0 to 100 km/h	-0,045565
big	dummy	-2,510469
income * big	'€95	0,0001738
inclusive value medium		0,1100573
inclusive value big		0,156294

Table 22: Coefficients of dummies for medium and big diesel cars (EU15, CH, NO)

country	coefficient
AT	0,1798926
BE	0,1938844
CH	-0,1913287
DE	-0,0358628
DK	-0,1285975
ES	0,1423761
FI	-0,0787181
FR	0,1537918
IE	-0,0129617
IT	0,0912006
LU	0,1335705
NL	0,0153049
NO	-0,1646315
PT	0,0863666
SE	0,2334205
UK	-0,0564373

For the central European countries, not sufficient sales data was available to include them in the model estimation. In order to use the model designed for EU15 (+ CH, NO), we assumed country-specific values for the diesel dummy in the medium/big model such that simulated shares are in line with the observation figures that are available.

Table 23: Coefficients of dummies for medium and big diesel cars (CZ, HU, PL, SI)

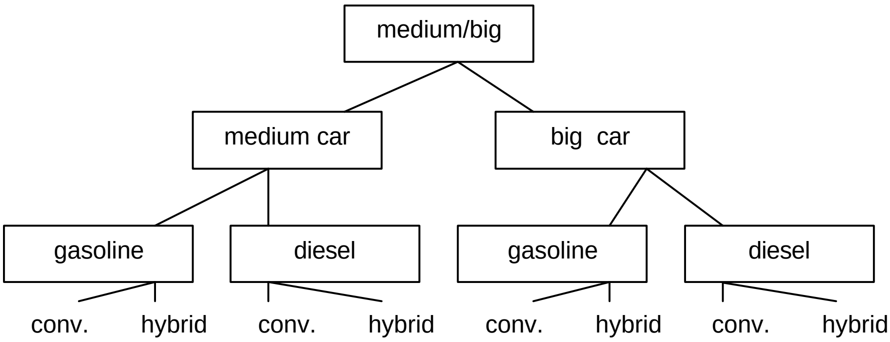
country	value of diesel dummy
CZ	0,05
HU	-0,1
PL	-0,15
SI	-0,1

Again comparing observed to simulated diesel shares, we see now that both shares are much closer to each other (as expected).

4.3.5.2 Hybrids

As discussed before, the model used for estimation (see Figure 13) is further extended in order to allow for the simulation of hybrid technologies' shares (see Table 18). For each conventional technology we introduce an hybrid equivalent. This is done by adding a new level to the nested structure.

Figure 14: Structure of nested logit model for medium and big technologies



The inclusive value coefficient has been assumed to be 0,2. This means that the probabilities of the conditional choice between hybrid or conventional make of a given technology are rather sensitive to the differences between both makes. Sensitivity analysis has shown that the value of 0,2 does lead to acceptable results.

The properties of hybrid technologies introduced in TREMOVE are based on a parallel (or combined) hybrid assumption both for diesel and gasoline cars, and for all size classes.
Baseline data for hybrid technologies are based on Verbeiren et al. 2003:

- purchase cost: an additional cost of € 5190 in 2000, € 5000 in 2010 and about € 3250 in 2020;
- fuel efficiency: a reduction of 20% for diesel and about 30% for gasoline

VUB-etec and ULB-ceese (2001) [47] assume repair and maintenance costs to be equal to the reference vehicle, but do not motivate this assumption.

In TREMOVE we assume that the same repair and maintenance factor apply for the equivalent hybrid and conventional technologies, which means a somewhat higher R&M cost for hybrids (proportional to purchase cost increase).
For the other variables (taxes, insurance as well as e.g. performance) we assume them defined the same way as for the reference conventional technology.

4.3.5.3 LPG

LPG cars are modelled as retrofit gasoline cars. Hence LPG cars are not included in the logit choice model. However, to account for the share of LPG cars in the vehicles stock, we assume a fixed share of the (non-hybrid) medium and big gasoline cars to be retrofit. This share is fixed exogenously to the observed 1995 share.

[47] VUB-etec, ULB-ceese (2001) Schone voertuigen - Verslag WP1 - "Definitie van het begrip Schone Voertuigen", Brussel.

4.3.5.4 Greece

Greece has been excluded from the model estimation because of the different choice Greeks face upon vehicle purchase: diesel technologies are not available for private car use (except taxis).
In the TREMOVE model, the model as estimated has been used in order to simulate medium-big shares for gasoline technologies. The diesel share however is fixed exogenously and kept constant over the modelling period.

4.3.5.5 Formulas and the coefficients used (medium/big cars)

Formulas are:

$$Share_{PCGM}=\frac{e^{\frac{V_{PCGM}}{\tau_1\cdot\tau_{medium}}}}{e^{IV_{GSLM}}}\cdot\frac{e^{\tau_1\cdot IV_{GSLM}}}{e^{IV_{medium}}}\cdot\frac{e^{\tau_{medium}\cdot IV_{medium}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

$$Share_{PCDM}=\frac{e^{\frac{V_{PCDM}}{\tau_1\cdot\tau_{medium}}}}{e^{IV_{DSLM}}}\cdot\frac{e^{\tau_1\cdot IV_{DSLM}}}{e^{IV_{medium}}}\cdot\frac{e^{\tau_{medium}\cdot IV_{medium}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

$$Share_{PCGHM}=\frac{e^{\frac{V_{PCGHM}}{\tau_1\cdot\tau_{medium}}}}{e^{IV_{GSLM}}}\cdot\frac{e^{\tau_1\cdot IV_{GSLM}}}{e^{IV_{medium}}}\cdot\frac{e^{\tau_{medium}\cdot IV_{medium}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

$$Share_{PCDHM}=\frac{e^{\frac{V_{PCDHM}}{\tau_1\cdot\tau_{medium}}}}{e^{IV_{DSLM}}}\cdot\frac{e^{\tau_1\cdot IV_{DSLM}}}{e^{IV_{medium}}}\cdot\frac{e^{\tau_{medium}\cdot IV_{medium}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

$$Share_{PCGB}=\frac{e^{\frac{V_{PCGB}}{\tau_1\cdot\tau_{big}}}}{e^{IV_{GSLB}}}\cdot\frac{e^{\tau_1\cdot IV_{GSLB}}}{e^{IV_{big}}}\cdot\frac{e^{\tau_{big}\cdot IV_{big}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

$$Share_{PCGHB}=\frac{e^{\frac{V_{PCGHB}}{\tau_1\cdot\tau_{big}}}}{e^{IV_{GSLB}}}\cdot\frac{e^{\tau_1\cdot IV_{GSLB}}}{e^{IV_{big}}}\cdot\frac{e^{\tau_{big}\cdot IV_{big}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

$$Share_{PCDB}=\frac{e^{\frac{V_{PCDB}}{\tau_1\cdot\tau_{big}}}}{e^{IV_{DSLB}}}\cdot\frac{e^{\tau_1\cdot IV_{DSLB}}}{e^{IV_{big}}}\cdot\frac{e^{\tau_{big}\cdot IV_{big}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

$$Share_{PCDHB}=\frac{e^{\frac{V_{PCDHB}}{\tau_1\cdot\tau_{big}}}}{e^{IV_{DSLB}}}\cdot\frac{e^{\tau_1\cdot IV_{DSLB}}}{e^{IV_{big}}}\cdot\frac{e^{\tau_{big}\cdot IV_{big}}}{e^{\tau_{medium}\cdot IV_{medium}}+e^{\tau_{big}\cdot IV_{big}}}$$

where

$$IV_{GSLM}=\ln\left(e^{\frac{V_{PCGM}}{\tau_1\cdot\tau_{medium}}}+e^{\frac{V_{PCGHM}}{\tau_1\cdot\tau_{medium}}}\right)$$

$$IV_{DSLM}=\ln\left(e^{\frac{V_{PCDM}}{\tau_1\cdot\tau_{medium}}}+e^{\frac{V_{PCDHM}}{\tau_1\cdot\tau_{medium}}}\right)$$

$$IV_{GSLB}=\ln\left(e^{\frac{V_{PCGB}}{\tau_1\cdot\tau_{big}}}+e^{\frac{V_{PCGHB}}{\tau_1\cdot\tau_{big}}}\right)$$

$$IV_{DSLB}=\ln\left(e^{\frac{V_{PCDB}}{\tau_1\cdot\tau_{big}}}+e^{\frac{V_{PCDHB}}{\tau_1\cdot\tau_{big}}}\right)$$

$$IV_{medium}=\ln\left(e^{\tau_1\cdot IV_{GSLM}}\;e^{\tau_1\cdot IV_{DSLM}}\right)$$

$$IV_{big} = \ln\left(e^{\tau_1 \cdot IV_{GSLB}} e^{\tau_1 \cdot IV_{DSLB}}\right)$$

and

$$V_{PCGM} = \beta_{acceleration} \cdot acceleration_{PCGM} + \beta_{LFC} \cdot \frac{LFC_{PCGM}}{GDPperINH}$$

$$V_{PCGHM} = \beta_{acceleration} \cdot acceleration_{PCGHM} + \beta_{LFC} \cdot \frac{LFC_{PCGHM}}{GDPperINH}$$

$$V_{PCDM} = \beta_{acceleration} \cdot acceleration_{PCDM} + \beta_{LFC} \cdot \frac{LFC_{PCDM}}{GDPperINH} + dum_{DSLcy}$$

$$V_{PCDHM} = \beta_{acceleration} \cdot acceleration_{PCDHM} + \beta_{LFC} \cdot \frac{LFC_{PCDHM}}{GDPperINH} + dum_{DSLcy}$$

$$V_{PCGB} = \beta_{acceleration} \cdot acceleration_{PCGB} + \beta_{LFC} \cdot \frac{LFC_{PCGB}}{GDPperINH} + dum_{BIG} + \beta_{income} \cdot GDPperINH$$

$$V_{PCDHB} = \beta_{acceleration} \cdot acceleration_{PCDHB} + \beta_{LFC} \cdot \frac{LFC_{PCDHB}}{GDPperINH} + dum_{BIG} + \beta_{income} \cdot GDPperINH$$

$$V_{PCDB} = \beta_{acceleration} \cdot acceleration_{PCDB} + \beta_{LFC} \cdot \frac{LFC_{PCDB}}{GDPperINH} + dum_{BIG} + \beta_{income} \cdot GDPperINH + dum_{DSLcy}$$

$$V_{PCDHB} = \beta_{acceleration} \cdot acceleration_{PCDHB} + \beta_{LFC} \cdot \frac{LFC_{PCDHB}}{GDPperINH} + dum_{BIG} + \beta_{income} \cdot GDPperINH + dum_{DSLcy}$$

The variables are:

- acceleration: acceleration time from 0 to 100 km/h
- LFC: lifetime cost in €2000 per km
- GDPperINH: GDP per inhabitant in €95

The values of the coefficients are:

- ß$_{acceleration}$ = -0,045565
- ß$_{LFC}$ = -0,4585391*40000
- ß$_{income}$ = 0,0001738 / 4
- t_1 = 0,2 (assumption)
- t_{medium} = .1100573 (estimated)
- t_{big} = .156294 (estimated)
- dum_{BIG} = -2,510469 (estimated)
- dum_{DSLcy} = country-specific (estimated)

Note that dum_{DSLcy} is the only country-specific coefficient in this model:

Table 24: Dummy values for the diesel – gasoline choice in the medium/big car choice model

AT = 0,1798926	FR = 0,1537918	NL = 0,0153049
BE = 0,1938844	FI = -0,0787181	NO = -0,1646315
CH = -0,1913287	(GR: no diesels)	PL = -0,15
CZ = 0,05	HU = -0,1	PT = 0,0863666
DE = -0,0358628	IE = -0,0129617	SE = 0,2334205
DK = -0,1285975	IT = 0,0912006	SI = -0,1
ES = 0,1423761	LU = 0,1335705	UK = -0,0564373

4.3.6 Base data

See §4.2.9 (small cars).

4.4 Moped

Mopeds have 2-stroke and <50 cc engines. All larger motorised two-wheelers are considered as motorcycles.

The moped vehicle stock is modelled in the same way as the most of the other vehicle stock models (moped scrappage module & moped purchase module).

Only 1 type of vehicle exists, so the module delivers the amount and age and related technology distribution of mopeds for each year.

Table 25: Moped vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type	vehicle technology
moped	gasoline	MP moped	RTMP1 - Conventional
			RTMP2 - Euro I
			RTMP3 - Euro II
			RTMP4 - Euro III

A moped model exists for each of the 21 countries.

4.5 Motorcycle

The motorcycle vehicle stock module is standard sale & scrappage model as described in the beginning of this chapter.

4.5.1 Motorcycle vehicle types

The motorcycle vehicle stock consists of 4 vehicle types:

Table 26: Motorcycle vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type	vehicle technology
motorcycle	gasoline	MC1 motorcycle -50cc	RTMC1 - Conventional
			RTMC2 - Euro I
			RTMC3 - Euro II
			RTMC4 - Euro III
		MC2 motorcycle 50-250cc	RTMC1 - Conventional
			RTMC2 - Euro I
			RTMC3 - Euro II
			RTMC4 - Euro III
		MC3 motorcycle 250-750cc	RTMC1 - Conventional
			RTMC2 - Euro I
			RTMC3 - Euro II

			RTMC4 - Euro III
		MC4 motorcycle +750cc	RTMC1 - Conventional
			RTMC2 - Euro I
			RTMC3 - Euro II
			RTMC4 - Euro III

Small motorcycles are not available in each country:

Table 27: Availability of motorcycle types per country

	MC1 motorcycle -50cc	MC2 motorcycle 50-250cc	MC3 motorcycle 250-750cc	MC4 motorcycle +750cc
AT	x	x	x	x
BE		x	x	x
CH	x	x	x	x
CZ		x	x	x
DE		x	x	x
DK	x	x	x	x
ES	x	x	x	x
FI	x	x	x	x
FR	x	x	x	x
GR	x	x	x	x
HU	x	x	x	x
IE		x	x	x
IT		x	x	x
LU	x	x	x	x
NL	x	x	x	x
NO		x	x	x
PL	x	x	x	x
PT	x	x	x	x
SE		x	x	x
SI	x	x	x	x
UK	x	x	x	x

4.5.2 Scrappage model

For motorcycles this is identical as for the other road vehicles (as cars).

4.5.3 Motorcycle stock

Motorcycle passenger-km data (=vehicle-km data as the occupancy rate is 1) is derived form the transport demand module. Motorcycle data is available for urban roads (metropolitan city and other cities), motorways and other roads. It is implicitly assumed that every type of motorcycle is driving on the same type of roads[48]. Large motorcycles do not drive relatively more often on motorways than small ones.

[48] This is assumed for busses, motorcycles, but not for HDV trucks. There we model separate shares of vehicles types for each road type. For cars, the distinction between vehicle types is already partly made in the transport demand module.

4.5.4 Sales of new motorcycles

The sales of new motorcycles are derived from a logit model. We decided to stick to the approach in TREMOVE 1.3a[49]. This approach 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.

The formula is:

$$Share_{tech} = \frac{e^{dum_{tech} - \beta_{cat} \cdot LFC_{tech}}}{\sum_{cat} e^{dum_{tech} - \beta_{cat} \cdot LFC_{tech}}}$$

with tech the vehicle type (e.g. MC2), and category is motorcycles.

The assumed values for $ß_{cat}$ is 5 for motorcycles.

Note that the dum_{tech} values are country specific, where for the $ß_{cat}$ one cross-country value applies.

For some countries, there were no logit model coefficients available. The solution was to use coefficient from a similar country.

Country with missing coefficients	*Coefficient source*
Austria	Germany
Portugal	Spain
Denmark	Finland
Sweden	Finland
Luxemburg	Netherlands
Belgium	Netherlands
Norway	Finland
Switzerland	Germany
Hungary	
Slovenia	
Czech Republic	
Poland	

The base data for 1995 has been derived from the TRENDS project.

[49] European Commission, Standard & Poors' DRI, K.U.Leuven. *The AOP II Cost – Effectiveness Study.* August 1999.

4.6 Light duty vehicle

This is again a classical sale & scrappage model with 2 vehicle types:

Table 28: Light duty vehicle types, fuel types, technologies

light duty vehicle	gasoline	LTG light duty vehicle gasoline	RTL1 - Conventional
			RTL2 - Euro I - 93 59 EEC
			RTL3 - Euro II - 96 69 EC
			RTL4 - Euro III - 98 69 EC Stage20
			RTL5 - Euro IV - 98 69 EC Stage20
	diesel	LTD light duty vehicle diesel	RTL1 - Conventional
			RTL2 - Euro I - 93 59 EEC
			RTL3 - Euro II - 96 69 EC
			RTL4 - Euro III - 98 69 EC Stage20
			RTL5 - Euro IV - 98 69 EC Stage20

Not all fuel types exist in each country:

Table 29: Availability of LDV vehicle types per country

	LTG light duty vehicle gasoline	LTD light duty vehicle diesel
AT	x	x
BE	x	x
CH	x	x
CZ	x	x
DE	x	x
DK	x	x
ES	x	x
FI	x	x
FR	x	x
GR	x	x
HU	x	x
IE	x	x
IT	x	x
LU	x	x
NL	x	
NO	x	x
PL	x	x
PT		x
SE	x	x
SI	x	x
UK	x	x

For each transport mode and each year t, the stock of LDVs surviving from the year t-1 is compared with the desired stock of vehicles needed by transport users in year t. The desired stock is derived from the transport demands per mode, as calculated in the demand module, and data on annual vehicle usage and load factors. The difference between desired stock and surviving stock is set equal to the total sales of LDVs for the considered mode in year t.

4.6.1 Scrappage model

For LDVs this is identical as for the other road vehicles (as cars).

4.6.2 Deriving the total number of vehicles from passenger-km

The transport demand module delivers ton-km. They are converted into vehicle-km using load factors consistent with SCENES.

The total number of vehicle-km is TREMOVE will be divided with the mileage per LDV vehicle (the number of km a vehicle drives during a year) to get the desired number of vehicles in a year.

Since we know the latter (number of vehicles) from the TRENDS baseline, we can easily derive the mileage per LDV vehicle in the base year. TRENDS also delivers their own estimated of mileage of per vehicle, but the absolute number is not used, since consistency with the transport demand figures is needed. They are used though for diversification of mileage figures between LDV vehicle. Data to estimate the decrease in mileage for older LDV vehicles was obtained from truck manufacturer IVECO.

4.6.3 Sales module

The sales of new LDVs are derived from a logit model. We decided to stick to the approach in TREMOVE 1.3a[50]. This approach 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.

The formula is:

$$Share_{tech} = \frac{e^{dum_{tech} - \beta_{cat} \cdot LFC_{tech}}}{\sum_{cat} e^{dum_{tech} - \beta_{cat} \cdot LFC_{tech}}}$$

with tech the vehicle type (e.g. LTG), and category is LDV.

The assumed values for $ß_{cat}$ is 25 for LDV.

Note that the dum_{tech} values are country specific, where for the $ß_{cat}$ one cross-country value applies.

4.6.4 Base data for 1995

Baseline data has been derived from TRENDS for the EU15 countries, from national sources for Switzerland and Norway, and from the N1 CO2 report for Hungary and Poland[51]. No data on Slovenia and Czech is available to the project team yet.

The sales of new motorcycles are derived from a logit model, derived from the TREMOVE 1_3a model (similar to the logit model in the car stock model, but with only lifetime costs as a parameter).

For some countries, there were no logit model coefficients available. The solution was to use coefficient from a similar country.

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50 European Commission, Standard & Poors' DRI, K.U.Leuven. *The AOP II Cost – Effectiveness Study.* August 1999.

51 RAND Europe, Forschunggesellschaft Kraftfahrwesen Aachen, Transport & Mobility Leuven. *Preparation of measures to reduce CO2 emissions from N1 vehicles.* Interim report to the European Commission, July 2002.

Country with missing coefficients	*Coefficient source*
Austria	Germany
Portugal	Spain
Denmark	Finland
Sweden	Finland
Luxemburg	Netherlands
Belgium	Netherlands
Norway	Finland
Switzerland	Germany
Hungary	
Slovenia	
Czech Republic	
Poland	

Portugal is a special case: there were no gasoline LDVs reported in the TRENDS baseline, so only diesel LDVs were modelled.

Another special case is Switzerland, where also gasoline HDVs were reported in the TRENDS database. In TREMOVE these were added to gasoline LDVs, as the same approach has been applied in TRENDS for the EU15 countries.

4.7 Heavy duty vehicle

4.7.1 Methodology

Basically the vehicle stock module for heavy duty vehicles (HDV) starts with the outputs of the demand module, which are figures on HDV ton-km per year disaggregated to road type (metropolitan, urban, motorway, rural) and period (peak hours or off-peak hours).

The outputs of the vehicle stock module are figures on vehicle usage to which emission factors can be applied.

The HDV truck vehicle stock model is very similar to that of other road vehicles. There is however one main difference: desired stock and sales are calculated separately for each HDV vehicle type, and not for the entire vehicle group. I.e. when it comes to stock modelling, each HDV vehicle type is considered as if it was a category on its own.

4.7.2 HDV vehicle categories

HDVs are divided into 4 weight classes:

Table 30: Heavy duty vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type	vehicle technology
heavy duty vehicle	diesel	HTD1 heavy duty vehicle 3,5-7,5 ton	RTH1 - Conventional
			RTH2 - Euro I - 91 542 EEC Stage I
			RTH3 - Euro II - 91 542 EEC Stage

vehicle category	fuel type	vehicle type	vehicle technology
			RTH4 - Euro III - 2000 Standards
			RTH5 - Euro IV - 2005 Standards
			RTH6 - Euro V - 2008 Standards
		HTD2 heavy duty vehicle 7,5-16 ton	RTH1 - Conventional
			RTH2 - Euro I - 91 542 EEC Stage I
			RTH3 - Euro II - 91 542 EEC Stage
			RTH4 - Euro III - 2000 Standards
			RTH5 - Euro IV - 2005 Standards
			RTH6 - Euro V - 2008 Standards
		HTD3 heavy duty vehicle 16-32 ton	RTH1 - Conventional
			RTH2 - Euro I - 91 542 EEC Stage I
			RTH3 - Euro II - 91 542 EEC Stage
			RTH4 - Euro III - 2000 Standards
			RTH5 - Euro IV - 2005 Standards
			RTH6 - Euro V - 2008 Standards
		HTD4 heavy duty vehicle +32 ton	RTH1 - Conventional
			RTH2 - Euro I - 91 542 EEC Stage I
			RTH3 - Euro II - 91 542 EEC Stage
			RTH4 - Euro III - 2000 Standards
			RTH5 - Euro IV - 2005 Standards
			RTH6 - Euro V - 2008 Standards

All 4 HDV types were modelled for each for the 21 countries.

All HDV trucks are considered diesel. In cases in which gasoline trucks occurred in fleet statistics, they were are assumed to be light duty vehicles (LDV).

Though industry representatives and the model team acknowledge that splitting op the +32 ton class into two or more heavy truck categories would add to the potential of the model, such a split proved not to be feasible. The main problems in this respect are the lack of appropriated categorised fleet data and fuel consumption and emission estimates rather than modelling difficulties.

For each vehicle category (#4) and each year (1995-2020), the vehicle stock module will provide the road usage (km) per age, technology and road type.

4.7.3 HDV truck scrappage sub model

For HDVs this has an identical structure as for the other road vehicles (as cars).

4.7.4 HDV truck sales sub model

4.7.4.1 Calculation of vehicle-km per year

From the transport demand module we get for each year T the number of **ton-km for 4 road types**:

HDV ton-km	metropolitan	peak & off-peak
HDV ton-km	other urban	peak & off-peak
HDV ton-km	other roads	peak & off-peak
HDV ton-km	motorways	peak & off-peak

Whereas for e.g. cars the allocation of total passenger-kilometres to the different car types is based upon the fleet statistics in the base year and the fleet forecasts in the other years, such an allocation approach is not feasible for heavy duty truck transport. The problem at stake is that treatment of unitised and combined trucks in the EUROSTAT-TRENDS fleet statistics[52] is not appropriate for TREMOVE. A typical example is Finland, where the share of heavy truck combinations in total traffic is obviously significant, while fleet statistics do not report trucks >32 tons.

Therefore, to allocate total truck vehicle-km to the different truck types in TREMOVE, the share of each truck type in total traffic is derived from other information sources. The data currently used are shares of truck types in total traffic on different road types as observed in Italian and German **road count data**[53]. If available, the model could be improved with road count data from other countries. These shares are assumed constant in the period 1995 – 2020. However it is modelled in a way, such that this assumption can be relaxed later on if needed.

Furthermore, in order to convert vehicle-kms by truck type to ton-kilometres by truck type, **load factors** (tons per truck type) for all HDV truck types are needed. These exogenous figures, also have been derived from the Italian and German datasets. Because the load factor is different for each truck type, an increase in e.g. the share of larger trucks in the HDV fleet will then lead to an increase in the average HDV load factor. The load factors by truck type are assumed constant in the 1995 – 2020 baseline, as SCENES included the assumption of constant load factors. However TREMOVE is modelled a way, such that this assumption can be relaxed later on if needed (e.g. with a trend in the load factors up to 2020).

Concluding, ton-km per road type is split into vehicle-km per road type and truck type with, in the baseline, constant road count shares and constant load factors per truck type.

4.7.4.2 Calculating mileage (km per vehicle per year) and needed vehicle stock

The base year mileages are calculated by dividing the vehicle-km by truck type (cfr. previous section) by the number of trucks in the statistics. Mileages for the forecast years have been set equal to the base year mileages. Modelling of mileages is thus similar to the approach for the other road vehicles. Data to estimate the decrease in mileage for older HDV vehicles was obtained from truck manufacturer IVECO and from UBA in Germany (the latter source was used for Germany).

It is important to note that dividing the TREMOVE vehicle-kilometres by truck type by the fleet statistics leads to unrealistic mileages per truck. As the fleet statistics tend to underestimate the number of heavy trucks (or combinations) and overestimate the number of lighter trucks, TREMOVE tends to overestimate heavy truck mileages and underestimate light truck mileages. This problem could be solved by extracting mileages exogenously from other sources (e.g. the available IVECO or UBA data). The base year fleet statistics would then be replaced by figures derived from the division of vehicle-kilometres by exogenous mileages. Obviously, this would lead to base year fleet composition figures that differ from the available statistics.

[52] For the non-EU15 countries similar problems occur in the fleet statistics

[53] Source: TRT.

4.7.4.3 Sales of new HDV vehicles

In the forecast years, the needed amount of trucks by type can now be derived from the number of vehicle-km and the **average mileage** (kilometres per vehicle per year) of a vehicle.

Once the desired number of HDV trucks in a year is known, and the number that is left over from the previous year (the lagged stock after scrappage), the HDV truck sales can be calculated directly per vehicle type.

Consequently, no sales logit model to split sales per category into sales per vehicle type is needed for HDVs, as the share of different HDV types in the stock is determined by the usage of different HDV types on each of the road types. Shifts from larger to smaller trucks are then possible in TREMOVE when shifts from e.g. motorway to urban transport occur, or when the load factors would change due to a policy influencing logistic processes.

4.8 Coach

The model is a standard sale & scrappage model. For each transport mode and each year t, the stock of coaches surviving from the year t-1 is compared with the desired stock of coaches needed by transport users in year t. The desired stock is derived from the transport demands per mode, as calculated in the demand module, and data on annual vehicle usage and occupancy rate. The difference between desired stock and surviving stock is set equal to the total sales of vehicles for the considered mode in year t.

Only 1 type of vehicle exists, so the sale & scrappage module delivers the amount and age distribution of coaches for each year.

Table 31: Coach vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type	vehicle technology
coach	diesel	BUS diesel	RTH1 - Conventional
			RTH2 - Euro I - 91 542 EEC Stage I
			RTH3 - Euro II - 91 542 EEC Stage
			RTH4 - Euro III - 2000 Standards
			RTH5 - Euro IV - 2005 Standards
			RTH6 - Euro V - 2008 Standards

A coach model exists for each of the 21 countries.

4.9 Bus

4.9.1 Vehicle types; fuel types and technologies

The bus model contains 2 vehicle types: a CNG bus and a diesel bus. The disaggregation by vehicle technologies is done by the bus age: from a certain year, a certain Euro class will be sold.

Table 32: Bus vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type	vehicle technology
bus	diesel	BUS diesel	RTH1 - Conventional
			RTH2 - Euro I - 91 542 EEC Stage I
			RTH3 - Euro II - 91 542 EEC Stage
			RTH4 - Euro III - 2000 Standards
			RTH5 - Euro IV - 2005 Standards
			RTH6 - Euro V - 2008 Standards
	CNG	BUS CNG	RTCNG bus CNG technology

A bus model exists for each of the 21 countries.

4.9.2 Bus scrappage sub model

This model is similar to the other road models. The parameters are calibrated with the TRENDS database.

4.9.3 Deriving the total number of vehicles from passenger-km

For each year t, the stock of small cars surviving from the year t-1 is compared with the desired stock of small cars needed by transport users in year t. The desired stock is derived from the transport demands, as calculated in the demand module, and data on annual vehicle usage, occupancy rates and load factors. The difference between desired stock and surviving stock is set equal to the total sales of small cars in year t.

4.9.4 The bus choice model

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)[54] 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 past research on discrete choice modelling of technology choice upon bus purchase, and no data for estimation seems to be available, we decided to design a small binomial logit choice model.

[54] Parker, R.S., Fletchall, H., Pettijohn, C. (1997) Truck operators' perspectives on use of alternative fuels, Transportation Research E, Vol. 33, No. 1, pp. 73-78.

A first assumption is that CNG buses are out of consideration when it comes to purchase of coaches, due to the range requirements that cannot be met by CNG buses. In TREMOVE we keep the share of coaches in overall bus sales constant to the observed 1995 level.

For the remaining buses, the choice between diesel and gasoline is modelled by the formulae:

$$Share_{diesel} = \frac{e^{-40 \cdot LFC_{diesel}}}{e^{-40 \cdot LFC_{diesel}} + e^{-40 \cdot LFC_{CNG}}}$$

$$Share_{CNG} = \frac{e^{-40 \cdot LFC_{CNG}}}{e^{-40 \cdot LFC_{diesel}} + e^{-40 \cdot LFC_{CNG}}}$$

with LFC_{tech} the lifetime cost ($€_{2000}$ per km) for tech.
The LFC coefficient (40) has been assumed and found to be realistic by sensitivity analysis.

Note that the level of the lifetime cost variable is very close for some country-year combinations, hence rather elevated CNG shares are modelled in these cases.

4.9.5 Lifetime cost baseline data

Baseline properties for both diesel and CNG buses have been based on literature.
For all buses we assume no taxes to apply (except excise duty on CNG sales). We also assume insurance to be zero[55].

4.9.5.1 Conventional diesel bus

Some reference values have to be fixed. Some data provided by different sources:

- Verbeiren et al. 2003[56]: purchase cost of: € 200.000
- PRIMES-transport[57]: purchase cost of BEF_{90} 4.601.098 (=$€_{2000}$ 140.000), annual operational and maintenance cost of $€_{2000}$ 27.250, an energy efficiency of 29,1 l/100km (average of buses and autocars)
- VUB-etec and ULB-ceese (2001)[58]: purchase cost of € 180.000, an energy consumption of 62,80 l/100km (urban) and an annual repair and maintenance cost of € 4.750
- Especially for the fuel consumption there seems to be a wide range between the observations. Some further communications with Vito.[59] on the topic resulted in yet another value of 39l/100km. This seems to be an acceptable value for non-coaches. For coaches however, a lower value of 30l/100km seems to be more appropriate (this has been confirmed by individual bus operators).

For TREMOVE, we assume the following values:

- purchase cost of € 200.000

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[55] In fact, buses do pay insurance costs, but these are estimated to be very small compared to other costs (De Ceuster, M.J.G. (2003). MIRA T-2003 Onderzoeksrapport Externe kosten. Rapport in opdracht van Projectteam Milieu- en natuurrapport Vlaanderen, Vlaamse Milieumaatschappij)

[56] Verbeiren S., De Vlieger I. en Pelkmans L. (2003) Duurzaamheidevaluatie van technologieën en modi in de transportsector in België. Deelrapport eerste screening (Taak A), Vito-rappport 2003/IMS/R086.

[57] Knockaert, J., Van Regemorter, D., Proost, S. (2002) Transport and energy scenarios for EU15 countries + Switzerland and Norway - an analysis with the PRIMES-transport model, Leuven.

[58] VUB-etec, ULB-ceese (2001) Schone voertuigen - Verslag WP1 - “Definitie van het begrip Schone Voertuigen”, Brussel.

[59] http://www.vito.be

- annual repair and maintenance cost factor of 0,2406 (compared to medium diesel passenger cars)
- an energy consumption of 39 l/100km (30l/100km for coaches)

4.9.5.2 CNG bus

The differences to the diesel technology are provided by several sources:

- Verbeiren et al. 2003: an extra purchase cost of 20% (i.e. € 40.000) and an energetic energy efficiency equal to the diesel technology
- PRIMES-transport (based on Markal[60]): an extra purchase cost of BEF_{90} 260.000 (i.e. $€_{2000}$ 7.900), an extra annual repair and maintenance cost of BEF_{90} 128.800 (i.e. $€_{2000}$ 3.900), an energetic consumption of 25% higher
- VUB-etec and ULB-ceese (2001): an extax price for CNG of € 0,69 per m^3, an extra purchase cost of between € 36.000 and € 45.000, an fuel consumption of 74,60 m^3/100km (this means actually an energetic fuel efficiency of about 6% higher than for diesel technology) and an extra repair and maintenance cost of about 20%.

Obviously, not all sources are in line. For TREMOVE we prefer to stick to the more recent SUSATRANS and VUB/ULB data:

- same repair and maintenance cost factor as for conventional diesel
- same energetic fuel efficiency
- an extra purchase cost of € 60.000[61]
- CNG price (extax) of € 0,69 per m^3 [62]

Excise taxes are based on DG TAXUD documents[63] and fixed to the 2004 level.

We assume CNG buses to be introduced in 2000. In the UK, the share of CNG busses is very low, as the CNG fuel price is extremely high compared to diesel.

4.10 Metro/tram

The demand module produces total tram and metro activity figures for passengers (see §3.10.3).

For (urban) tram and metro the vehicle stocks are not explicitly modelled as only one type of trams and metros is assumed to be available in each of the countries (i.e. 1 emission factor for trams and 1 for metro in each country).

Table 33: Metro/tram vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type
metro/tram	electric	metro
		tram

[60] Markal database by Vito
[61] This value is higher than in literature, however, literature values typically result in overall lifetime costs for CNG that are lower than diesel, which seems to be unacceptable
[62] VUB/ULB assume a 37,1 MJ/m^3 energy density
[63] European Commission (2004) Excise Duty Tables - Part II - Energy products and Electricity, Brussel

Therefore, emissions and energy consumption are calculated directly from passenger-km data, by applying observed German and Swiss occupancy rates and estimated average energy consumption factors per vehicle-kilometre. We've assumed the occupancy rates constant over time.

The fraction of tram and metro in the total passenger rail transport is assumed to be constant over time, with different values for each country, region and period.

4.11 Passenger train

The rail vehicle stock turnover module follows the same general approach as the road vehicle turnover model like for road, but a number of differences should be highlighted.

4.11.1 Train vehicle types

The vehicle types that are distinguished in the rail vehicle stock modelling are:

Table 34: Passenger train vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type
passenger train	train diesel	passenger locomotive diesel
		passenger railcar diesel
	electric	passenger locomotive electric
		passenger railcar electric
		passenger high speed train electric

We used information for the powered stock[64] as well as for the transport stock[65] by railway companies. The data of the companies can be attributed to the countries. With respect to the emissions, the powered stock is of higher importance than the transport stock. The emissions of diesel trains can be calculated directly (as direct emissions), the emissions of the electric trains are calculated indirectly (via energy consumption).

UIC and TRENDS data suggests that not all train types are being used in all countries. Consistent with the TRENDS database[66], the following train types were used per country:

Table 35: Availability of passenger train types per country

	locomotive diesel	railcar diesel	locomotive electric	railcar electric	high speed train electric
AT	x	x	x	x	
BE	x	x	x	x	x
CH			x	x	
CZ	x	x	x	x	x
DE	x	x	x	x	x
DK	x	x	x	x	
ES	x	x	x	x	x
FI	x		x	x	x

64 For this purpose the 'International Railway Statistics' and the 'Supplementary Statistics' of UIC are used as primary main source.

65 Tables A25 – A27 of the 'Supplementary Statistics' of UIC.

66 Georgakaki A., Coffey R., Sorenson S.C. (2002) *Transport and Environment Database System (TRENDS) . Detailed Report 3: Railway Module.* Project funded by the European Commission – Directorate General for Transport and Energy.

FR	x	x	x	x	x
GR	x	x			
HU	x	x	x	x	x
IE	x	x		x	
IT	x	x	x	x	x
LU	x	x	x	x	
NL	x	x	x	x	x
NO	x	x	x	x	
PL	x	x	x	x	x
PT	x	x	x	x	
SE		x	x	x	x
SI	x	x	x	x	x
UK	x	x	x	x	

4.11.2 Rail base data for 1995

In principle, the TRENDS data (TRansport and ENvironment Database System) is used for the base year. TRENDS (version 1) has been finalised in October 2002.

The main source for the data was the Eurostat New Cronos Rail database, with supplementary data provided from the International Union of Railways (UIC), and from national sources. The few gaps in past data were – if necessary – filled by Eurostat by interpolation or by linear or exponential trends, as appropriate for tons, tkm, passengers and pkm. A similar approach was used for the train-km, where the gaps were more numerous.

Particular assumptions had to be made with respect to High Speed Train fleets. The countries considered to have HST train traffic are the following: France since 1981, Germany since 1992, Sweden since 1995, Belgium, Spain, Finland, Italy and the Netherlands since 1996. The results were adjusted to equal totals on the basis of ratio to total, thus ensuring internal coherence. First high speed trains in the New Member States are assumed to enter the market around the end of this decade.

The stock of HSTs in 1995 is calculated form UIC 2000 figures, by adjusting for lower vkm (TRENDS) in 1995.

In the next table, the train stock for 1995 can be found. Note that this is the total stock for both passenger and freight trains. Disaggregation of fleet statistics to passenger and freight trains has been performed by assuming equal mileages for passenger and freight trains of the same type.

In the TREMOVE input database[67], a more extended table can be found, which includes an age distribution per train type. This age distribution has been taken from UIC[68]. The UIC age distribution is not per vintage year, as for road vehicles, but per 10 years: <1960, 60s, 70s, 80s, 90-94, >95 (6 classes). The data is converted to a per-year basis by assuming uniform distributions within each 10-year class.

[67] See www.tremove.org

[68] Source: UIC 2000, supplementary statistics, Tab A24.

Table 36: Total train stock per country and per train type (passenger + freight) in 1995

	locomotive diesel	railcar diesel	locomotive electric	railcar electric	hst electric	Total
AT	469	138	695	225	0	1.527
BE	593	20	376	590	0	1.579
CH	303	0	1.291	272	0	1.866
CZ	1.775	786	1.085	83	0	3.729
DE	5.566	704	3.574	1.909	92	11.845
DK	255	187	22	319	0	783
ES	580	136	525	615	0	1.856
FI	550	0	111	100	0	761
FR	2.980	738	2.134	1.139	303	7.294
GR	355	230	0	0	0	585
HU	889	268	493	20	0	1.670
IE	114	17	0	40	0	171
IT	1.169	840	2.012	616	0	4.638
LU	57	2	19	32	0	110
NL	333	116	202	559	0	1.210
NO	118	26	127	138	0	409
PL	2.589	41	1.785	1.119	0	5.534
PT	118	26	127	138	0	409
SE	348	81	440	272	38	1.179
SI	123	83	95	30	0	331
UK	376	194	291	5.000	0	5.861

4.11.3 Deriving the total number of trains from passenger-km

The number of vehicle-km is calculated from passenger-km using occupancy rates. Occupancy rates have been calculated using TRENDS as well as UIC data for the 1995 base data. The occupancy rates in TREMOVE, as well as their evolution over the 1995-2020 period, are consistent with the overall evolutions in TRENDS.

The number of trains is derived form the number of vehicle-km using average mileages.

As for road vehicles, the average mileages (vkm per vehicle per year) for the train types are calculated for 1995 by comparing vehicle-kilometres (from the previous calculation) to the available number of vehicles (from the 1995 base data).

The annual mileages for each train type are assumed to be constant over time, up to 2020. Desired mileage is also assumed to be equal for trains of different vintages (i.e. no mileage decrease as for cars).

4.11.4 Scrappage of old trains

All trains are assumed to be scrapped after 40 years. The option to implement a more elaborate scrappage function as soon as appropriate data becomes available is foreseen in the model structure.

4.11.5 Trains sales model

By comparing the needed train stock with the stock remaining from the previous year, ie stock in preceding year minus scrappage, the total number of new trains to be purchased is estimated.

In order to determine the stock *composition* by train type in each year the shares of each of the different train types in the total train acquisitions has to be estimated.

These sale shares are determined such that the 1995-2020 evolution of the train stock is consistent with the long-term trend in TRENDS[69]. In other words, the module is set up to be in line with the share of the different train types in the total vehicle-kilometres in TRENDS for the 1995-2020 period. Note that, in the short term, consistency with TRENDS is not always assured, as the extent of the yearly changes in train stock composition in TREMOVE are limited by the rate of turnover of the train stock (i.e. the scrappage rate and the age distribution).

4.12 Freight train

The freight train model has exactly the same structure as the passenger train model.

The freight train types are:

Table 37: Freight train vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type
freight train	train diesel	freight locomotive diesel
		freight railcar diesel
	electric	freight locomotive electric
		freight railcar electric

UIC and TRENDS data suggests that not all train types are being used in all countries. Consistent with the TRENDS database, following adaptations were made :

- There are only freight railcars in some countries.
- Greece and Ireland: only diesel trains, no electric trains.

Table 38: Availability of freight train types per country

	freight locomotive diesel	freight railcar diesel	freight locomotive electric	freight railcar electric
AT	x		x	
BE	x		x	x
CH	x		x	
CZ	x		x	x
DE	x		x	
DK	x		x	
ES	x		x	
FI	x		x	
FR	x		x	x
GR	x			
HU	x		x	x
IE	x			

[69] For accession countries the evolution of the train stock is such that it is in line with the EU average by 2020.

	freight locomotive diesel	freight railcar diesel	freight locomotive electric	freight railcar electric
IT	x		x	
LU	x		x	
NL	x		x	x
NO	x		x	
PL	x		x	x
PT	x		x	
SE	x		x	
SI	x	x	x	x
UK	x		x	

4.13 Inland ship

4.13.1 Scope

An inland waterway stock module does not exist for all countries. Only the countries for which SCENES can provide data are included:

- Austria
- Belgium
- Switzerland
- Czech republic
- Germany
- France
- Hungary
- Italy
- Netherlands
- Poland

4.13.2 Calculation of the vehicle-kilometers

From TREMOVE demand module the ton-kilometres per commodity type and short/long distance figures are derived for 1995 to 2020.

These are disaggregated into ton-kilometres per ship type, commodity type and short/long distance per year, using allocation keys.

Total vehicle-km by inland ship type is calculated by combining ton-km and exogenous load factors. The number of vessels itself is not modelled.

Finally, what is needed for emission calculations is the number of vehicle-km by vessel type and configuration (i.e. the kind of propulsion technology) in each country. Therefore, vehicle-km is further split to configurations by using the 'configuration matrix', which will be explained further in this chapter.

4.13.3 Base case modelling for vehicle usage (vkm per ship type)

From SCENES and the TREMOVE demand module we get ton-kilometres figures for 1995 to 2020 per commodity type and short/long distance. From TNO we get load factors for the different vessels and an allocation key to allocate the ton-kilometres to the different vessel types. Using these load factors and allocation keys from TNO and the traffic volumes from SCENES and the TREMOVE demand module we calculate the ton-km and vehicle-km for each ship type in each country.

The ton-kilometres figures for 1995 to 2020 from SCENES and the TREMOVE demand module are disaggregated to bulk, general cargo and unitised and disaggregated to short distance and long distance trips. The differentiation between peak and off-peak inland waterway trips is available from the demand module, but is not used in the vehicle stock and emissions module.

The inland waterway vehicle stock module uses the vessel classification given in the next table.

Table 39: Inland ship vehicle types, fuel types, technologies

vehicle category	fuel type	vehicle type
inland ship	ship gasoil	Dry Cargo Ship (1) -250 ton
		Dry Cargo Ship (2) 250-400 ton
		Dry Cargo Ship (3) 400-650 ton
		Dry Cargo Ship (4) 650-1000 ton
		Dry Cargo Ship (5) 1000-1500 ton
		Dry Cargo Ship (6) 1500-3000 ton
		Dry Cargo Ship (7) +3000 ton
		Pusher Barge (1) -250 ton
		Pusher Barge (2) 250-400 ton
		Pusher Barge (3) 400-650 ton
		Pusher Barge (4) 650-1000 ton
		Pusher Barge (5) 1000-1500 ton
		Pusher Barge (6) 1500-3000 ton
		Pusher Barge (7) +3000 ton
		Tanker Ship (1) -250 ton
		Tanker Ship (2) 250-400 ton
		Tanker Ship (3) 400-650 ton
		Tanker Ship (4) 650-1000 ton
		Tanker Ship (5) 1000-1500 ton
		Tanker Ship (6) 1500-3000 ton
		Tanker Ship (7) +3000 ton

Three smallest classes = classification as in DGTREN datasets.
The 4 largest classes = further disaggregation of >650 class as in Dutch data.

TNO delivered load factor figures and an allocation key to allocate ton-kilometres by commodity type to the different vessel types and weight classes. This information was derived from Dutch government statistics (i.e. CBS database). Different load factors and allocation keys are specified by commodity, domestic vs. international and vessel type, as differences between commodities and domestic vs. international are important.

For long distance trips, load factors and allocation keys are calculated from the Dutch data on all international vessel trips starting, going to or going through the Netherlands. This dataset includes ca. 70% of total international trips in Europe, thus can be used to estimate allocation keys for long distance trips in all countries.

For short distance trips, data on load factors and allocation key are available for the Netherlands only (based on data on domestic trips in the Netherlands). For the other countries, an elaborate procedure has been set up to extrapolate the Dutch short distance allocation keys to other countries. This procedure takes into account differences in the inland waterway networks over countries. In other words, in countries with a high share of small and narrow waterways, the shares of smaller ships will increase compared to the Netherlands and vice versa.

The Dutch data refers to 1995 and 2000. 1996-1999 figures were calculated by linear interpolation. For 2001-2020, a trend in the allocation keys is used, based on Dutch government forecasts on the evolution of the inland waterway fleet composition (which indicates a trend towards larger ships). Again an elaborative procedure has been set up to perform the allocation key forecasts.

Starting from the ton-km figures from the transport demand module and the allocation keys, we calculate ton-kilometres per vessel type, commodity type and trip length per year. Total vehicle-km by vessel type is calculated by combining ton-km and load factors.

Finally, what is needed for emission calculations is the number of vehicle-km by vessel type and configuration (i.e. the kind of propulsion technology) in each country. Therefore, vehicle-km is further split to configurations by using the 'configuration matrix'.

4.13.4 Calculations for the vehicle (engine) stock module and policy simulation

4.13.4.1 Simulated policies

In TREMOVE the growth rate in bulk – unitised – gen. cargo ton-kilometres is taken from the demand module and depends on the policy scenario. Indeed, the demand module enables to assess the effects of policies that affect generalised prices of inland waterway transport on inland waterway transport demand. Such policies might be for example: fuel taxes, speed limits, emission taxes, and yearly vehicle taxes.

In TREMOVE we will not enable assessment of policies that directly affect fleet composition, load factors and shares of ton-km transported by the different vehicle types. I.e. load factors and shares of ton-km transported by the different vehicle types are exogenous and will be always equal to the base case values. Modelling policies that would change load factors is not feasible as load factors depend on industries logistic practices that are not represented in our model. Modelling policies that would affect changes in the shares would necessitate modelling the turnover and sales of different vessel types (tanker, pusher, cargo) and sizes (weight class). This is infeasible in TREMOVE, as it would require detailed cost data per vessel type (which is not available). Moreover the choice between vessel types is not only affected by relative costs, but is also determined by industry practices, size of the waterways, detailed type of the good, etc… which are all factors that cannot be explicitly represented in an aggregate model as TREMOVE.

Policies that we will explicitly include in TREMOVE will be policies acting on fuel choice and fuel specification (e.g. low sulphur fuel), technology standards & emission taxes leading to the use of add-on technologies as catalytic converters or de-NOx equipment and policies that promote the use of more efficient engines. Thus, we will model that, although the fleet composition is not sensitive to policies, the fuel, engines and after-treatment technologies used on each of the vessel types depends on the policy environment.

4.13.4.2 Engine stock turnover/purchasing decision

The vehicle fleet for inland waterways is not be modelled explicitly, because the fleet cannot be allocated to a country. Moreover, as for most modes, it is not the type of vehicle used that is important for the emission, but the engine used by that vehicle. In this matter, ships take in a special position. Most ships are able to replace their engine because of the long lifetime of the ships. Experts agreed that this replacement is done every 10 years. Therefore we prefer an **engine stock model**, rather than a vehicle stock model. Unlike in the road module, we assume that purchasing decisions of new engines will only depend on the costs of this engine during its lifetime (10 years). We write off every cost to money cost per vehicle-kilometre.

Following components are important for the purchasing decision:
- Fuel resource costs.
- Fuel taxes.
- Additional costs related to the usage of improved engines[70].
- Additional costs related to usage of the after-treatment equipment.
- Non-fuel vehicle related taxes (such as additional emission taxes, taxes on specific ship types, etc.). These will probably be zero in the base case, as there is currently no legislation yet and because these are mostly not important for the purchasing decision of an engine.

Commodity type and short distance vs. long distance further aggregate each of these cost components to costs in euro per ton-km, through the allocation key figures and the load factor figures. These cost figures are included in the model as a component of the money costs per ton-km specified in the previous section.

4.13.4.3 Modelling fuel-engines after-treatment technology configurations

For each ship type a set of fuel types is available as well as a set of engine types and after-treatment equipment. Thus ships can have different propulsion configurations as e.g. fuel1.engine2.equipment1 or fuel2.engine1.equipment1.

In the base case model, only (one) ‘conventional’ configuration(s) is available. In the simulation model, also new and unconventional configurations can be included for the sake of (technology or fuel) policy assessment.

For each possible configuration, the following information will be specified in the data files:
- Fuel resource cost in euro per litre.
- Fuel tax in euro per litre.
- Year in which the configuration becomes available.
- Reduction in fuel consumption (litre per vehicle-km) compared to base case configuration in %, i.e. abatement.
- Reduction in emissions (grams per vehicle-km) compared to base case configuration in %, i.e. abatement level.
- Additional cost of the engine type compared to the base case configuration in EURO per vkm.

[70] This is zero for the base case engine technology, in simulations it is calculated from the additional cost of engine improvement, engine lifetime and mileage per vehicle per year (or engine).

- Additional cost of the after-treatment equipment compared to the base case configuration in euro per vkm.

For each vessel type, a **configuration matrix** is specified, both for the base case and for the simulation, which indicates the share of different fuel.engine.equipment configurations in the vehicle stock in each year. An example of a configuration matrix is given in the next table:

Table 40: Configuration matrix

	1995	1996	…	2020
Fuel1.engine1.equipment1	1,00	1,00		0,95
Fuel1.engine1.equipment2	0,00	0,00		0,05
…				

As TREMOVE assumes that mileage per ship is equal over all configurations for each ship type, the vehicle-km by configuration can be derived from the vehicle-km of the vessel type. Note also that load factors are constant and equal over configurations, thus ton-km by ship type and configuration can be calculated.

In the base case as well as in the simulation, the share figures in the technology matrix for each year and each vessel type will be determined by solving a 'technology-cost minimising problem', which has the following structure:

Minimise the average cost per vehicle-kilometre [in EURO per vkm]
Subject to:

1. The average cost per vehicle-kilometre = weighted average fuel res. cost per vkm (weighted over configurations) + weighted average fuel tax per vkm + weighted average additional cost of the engine type + weighted average additional cost of the after-treatment equipment + non-fuel vehicle-related taxes per vkm (e.g. emission tax) + costs related to accelerated replacement/scrappage
2. Sum over the configurations = 1
3. Shares are always positive, and 0 if the configuration is not (yet) available
4. Costs related to accelerated replacement/scrappage = residual value of the engine or equipment in case it is replaced/scrapped before the end of its lifetime.

Step (4.) is needed to introduce a kind of engine/equipment turnover rate. I.e. it specifies that engines/equipment are replaced at the end of their lifetime, except if replacing the engine/equipment earlier by better (cleaner) technologies would lead to benefits (e.g. saving of emission taxes) that offset the cost (i.e. residual value of the engine).
When needed, step (4.) could be replaced or accompanied by other equations, which represent limits to the pace of engine/equipment market penetration.

Once the configuration matrix shares are determined for a year, the weighted average costs in euro per vehicle-km for a vessel type can be calculated.

4.13.5 On inland waterway national vehicle stocks

Full information on vehicle stock composition (number of ships registered by type) is available for the following countries.

- France (2000)

- Belgium (1995 and 2000)
- Netherlands (1995 and 2000)

For other countries, partial or no data on registered inland ships by type is available.

The model is set up however to enable estimation of vehicle-kilometres and emissions by ship type, without modelling explicitly the vehicle stocks in each country. Indeed, as in each country many ships that are registered in other countries are used, it is not feasible to link the inland waterway activity in a country to this countries vessel stock.

Therefore, stock data was not explicitly included in the TREMOVE model but is only used as additional information, in case we model country specific policies or for validating base case outcomes figures on vehicle-km by vehicle type.

4.14 Plane

For air transport, no vehicle stock has been modelled. Emissions and fuel consumption for aircrafts are directly computed from passenger-km.

Table 41: Plane vehicle types, fuel types, technologies

plane	kerosine	Air distance (1) -500 km
		Air distance (2) 500-1000 km
		Air distance (3) 1000-1500 km
		Air distance (4) 1500-1000 km
		Air distance (5) +2000 km

Aircraft activity data by aircraft type and trip length is available through the AVIOPOLL database developed in TRENDS[71] in collaboration with EUROCONTROL and EUROSTAT.

[71] pSIA-Consult (2002) *Transport and Environment Database System (TRENDS) . Detailed Report 4 : Aviation Module* Project funded by the European Commission – Directorate General for Transport and Energy.

4.15 Overview of the baseline results

The 2 figures below give an overview of the car and rail fleet in EU15. More detail can be obtained from the baseline Access database.

Figure 15: EU15 car fleet

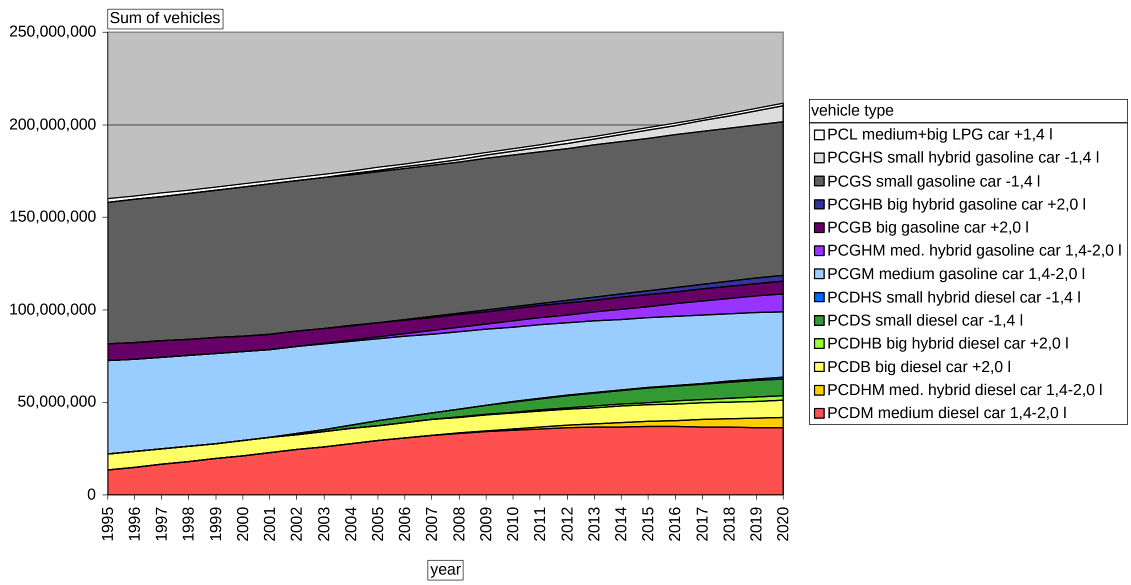
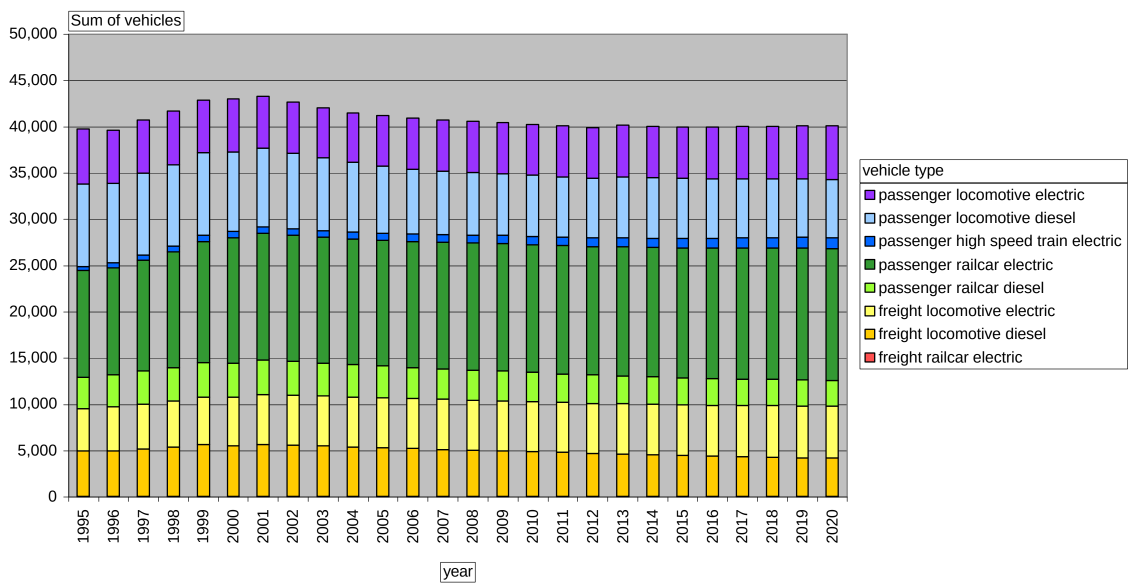


Figure 16: EU15 train fleet



The technology penetration for medium/big cars and mopeds and motorcycles can been seen in the figures below.

Figure 17: Technology penetration for medium and big cars in EU 15

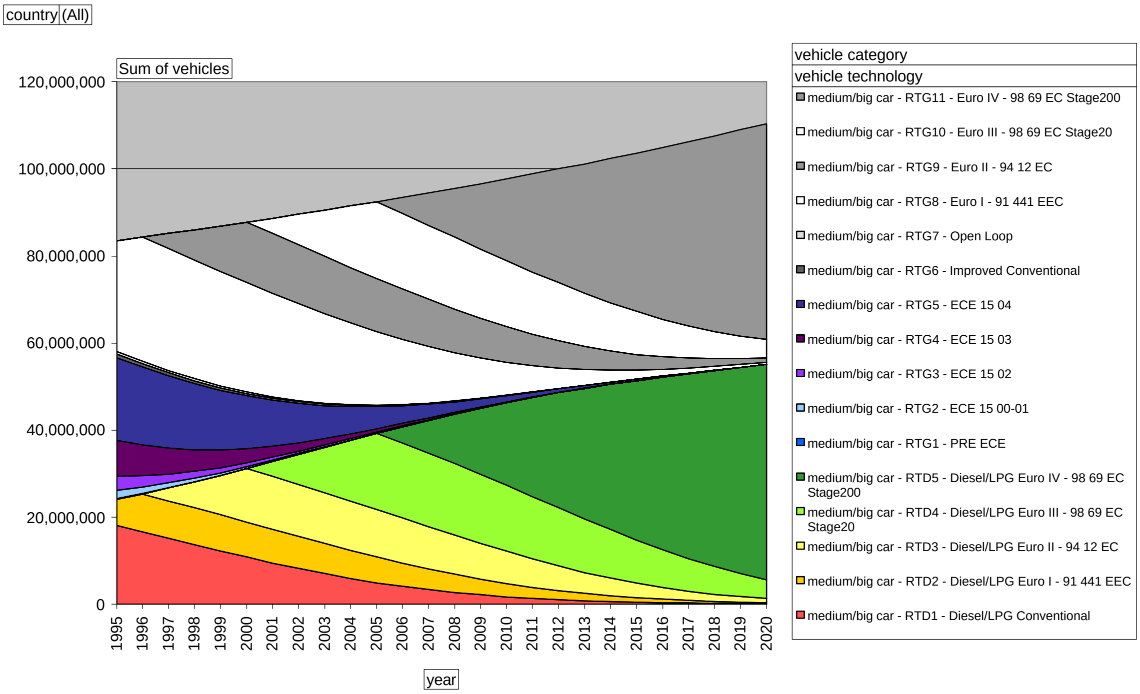
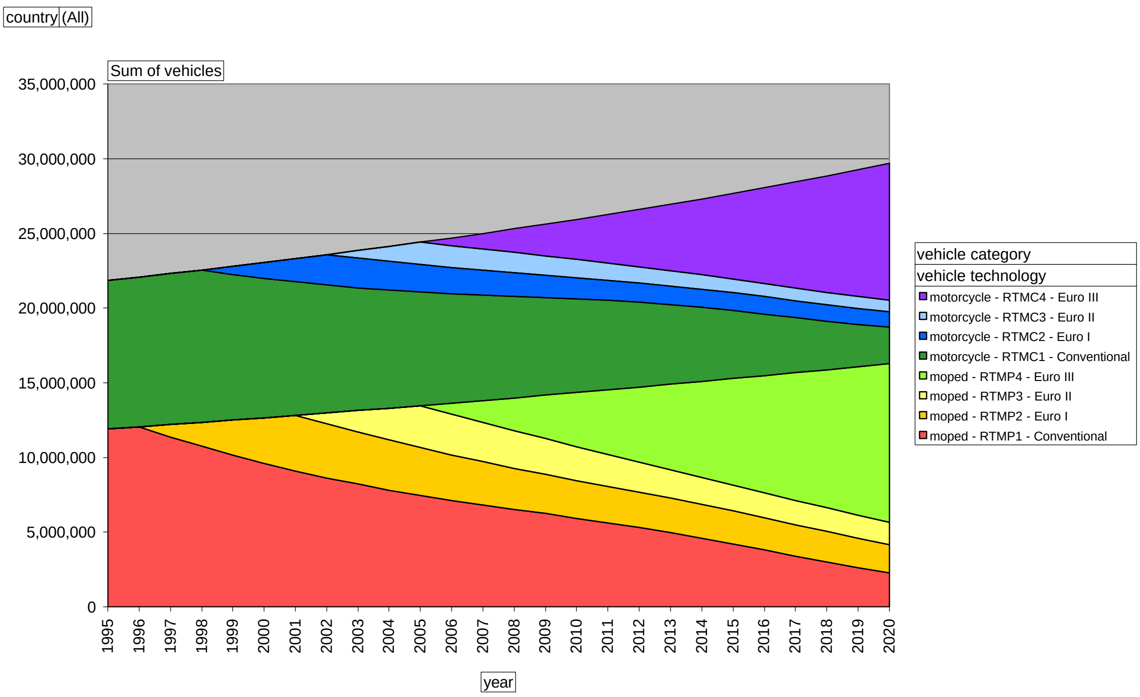


Figure 18: Technology penetration for mopeds and motorcycles in EU 15



5 The fuel consumption and emissions module

5.1 Introduction: data availability and calculation methods

Estimates of transport emissions on a national basis, and more locally as part of air pollution impact studies, have been made in some countries since the 1970s. The methods employed have been improved and developed since then, through an increase in the amount, type and quality of available data. With respect to road transport emissions, there is a relatively large amount of information available although this should not imply that there are no omissions or uncertainties in these data. With respect to road transport, the scope of the available data allows for a relatively detailed methodology, which is not possible to non-road transport modes. However, the general philosophy of emission modelling is common across the transport modes[72].

5.1.1 Emission data availability

A large number of different outputs produced by transport activities are generally considered as pollutants. The emission factors for some of them have been investigated in detail, and are therefore well known, while for others only limited data exist, which are frequently insufficient to be representative of the relevant activities. Consequently, currently soundly based emission factors are available for some of the pollutants and some of the vehicle categories; for others only order of magnitude estimates of the emission factors are available, while for the rest the available information is insufficient.

The next table gives an overview on the current availability of road transport emission factors, and indicates whether or not they are included in TREMOVE version 2.2 :

- Level 1 includes the pollutants for which the existing data allow for the definition of representative emission factors with a high degree of certainty[73]**.**
- Level 2[74] includes the pollutants for which the existing emission factors cannot be considered representative: emission factors given for level 2 pollutants are to be considered only as an indication of the order of magnitude.
- Level 3 includes the pollutants for which there are only very few data and the resulting emission factors are not robust.

[72] Meet, 1999.

[73] The term certainty as used here is relative to the quality of data for levels 2 and 3. No emission factors are known with absolute certainty.

[74] The distinction between levels 2 and 3 is not clearly defined as there is no definite point at which the degree of uncertainty in the data precludes the specification of an approximate emission factor. New data are continuously becoming available, and thus the transfer of pollutants between these uncertainty levels is on-going.

Table 42: Pollutant categories according to the present knowledge of emission factors

Pollutant	Level 1	Level 2	Level 3
Energy consumption	T		
CO_2	T		
CO	T		
VOC	T		
NO_X	T		
PM	T		
SO_2	T		
Pb	T (not in v 2.2)		
N_2O		T	
CH_4		T	
NMVOC		T	
VOC speciation (e.g. benzene etc.)		T	
PM size distribution			T (not in v 2.2)
NH_3			T (not in v 2.2)
H_2S			T (not in v 2.2)
NO_2			T (not in v 2.2)
HM			T (not in v 2.2)

Currently, the EU funded projects ARTEMIS[75] and PARTICULATES[76] are further extending the knowledge on emission factors for all transport modes and all pollutants. Once completed, ARTEMIS project is expected to provide emission factors to the TREMOVE model for all modes and pollutants (factors for particulate matter will be taken from the PARTICULATES project)[77].

Since the final ARTEMIS results are not available yet, the TREMOVE 2.2 fuel consumption and emission module is based upon the COPERT III emission calculation methodology for the calculation of road transport emissions. The new road vehicle fuel consumption and emission module thus is an update of the module in TREMOVE 1.3a – the model version used in the Auto-Oil II Program[78] – which was based upon COPERT II. Additions to the COPERT III methodology included in TREMOVE 2.2 , e.g. in the context of the car industries voluntary agreement to reduce CO_2 emissions, will be discussed in the following sections. Emission factors for other modes where derived from intermediate ARTEMIS outcomes and other sources, as indicated in the remainder of this section.

5.1.2 Calculation methods for energy consumption and emissions in TREMOVE 2.2

As in most similar studies, a variety of methods is used to calculate energy consumption and emissions in TREMOVE. They depend on the pollutant, the transport mode, and the vehicle type, and are inevitable because of the varying amounts and quality of data in each case. The methods may be grouped into four classes:

- *Calculation based on transport activity.* This is the basic method for the more common emissions from road vehicles and for the energy consumption for non-road modes. The emissions calculated in this way may include hot emissions, trip start emissions when the engine is not fully warmed up, and evaporative emissions

[75] ARTEMIS website: *http://www.trl.co.uk/artemis/*

[76] ARTEMIS develops new emission factors for all modes and all pollutants; PARTICULATES specificly focusses on PM size distributions

[77] Due to delays in the ARTEMIS project the update of TREMOVE to ARTEMIS factors will not be possible in the context of the Clean Air For EUROPE (CAFE) program

[78] European Commission, Standard & Poors' DRI, K.U.Leuven. *The AOP II Cost – Effectiveness Study.* August 1999.

- *Calculation based on energy consumption.* This is the standard method for emissions from non-road modes, and also for SO_2 emissions from road vehicles. The types of emission included (hot, start, evaporative) depend on those included in the energy consumption estimate
- *Carbon balance calculations.* Calculations of fuel consumption or carbon dioxide emissions may be based on the equation representing the mass balance of carbon in the fuel and its combustion products.
- *Pollutant specific calculations.* Some pollutants are sub-categories of others (e.g. VOC species are part of total VOC). Estimates may be made from the main pollutant and details on speciation and size distribution. Hot, start and evaporative emissions may be included.

The next table gives a more detailed indication of the pollutants covered in TREMOVE and the applied calculation methods.

Table 43: Methods of calculating pollutant emissions according to the transport mode and engine type.

		Combustion engines			
		Road	Rail	Water	Air
Energy consumption		2	2	2	2
Exhaust and evaporative emissions	CO_2	5	5	5	5
	CO	2, 3	4	4	4
	VOC	2, 9	4	4	4
	NO_X	2, 3	4	4	4
	PM	2, 3	4	4	
	SO_2	4	10	10	10
	N_2O	2, 3		4	
	CH_4	2, 6		4,6	
	NMVOC	2, 6		4,6	
	C_6H_6	7			

Key:
1 Fuel consumption = f(CO, CO_2, VOC, PM) [carbon balance]
2 Calculation according to the activity
3 Emission = hot emission + start emission
4 Emission = f(energy consumption) [energy specific emission factors]
5 Emission = f(fuel consumption, CO, VOC, PM) [carbon balance]
6 NMVOC + CH_4 = VOC
7 VOC species = f($VOC_{exhaust}$, $VOC_{evaporative}$, $VOC_{composition}$)
8 PM size = f(PM, $PM_{size\ distribution}$)
9 Emission = hot emission + start emission + evaporative emission
10 Emission = f(fuel consumption, sulphur content of fuel)

5.2 Road transport emissions

TREMOVE 2.2 uses the COPERT III+ module. Indeed, since the expected ARTEMIS methodology is not available yet, the road emission calculations are based on the existing COPERT III methodology. The module used in TREMOVE 2.2 is referred to as COPERT III+, as it includes some extensions and updates of the COPERT III methodology.

For each year the TREMOVE vehicle stock module produces figures on the vehicle-kilometres and vehicle speeds for road transport disaggregated to:

- Vehicle type
- Fuel type
- Vehicle technology
- Vehicle age (age and technology are related to each other)

- Network (urban road, non-urban road, motorway)
- Model region (metropolitan, other cities, non urban)
- Period of day (peak or off-peak)

The COPERT III+ module then calculates fuel consumption and vehicle emissions for each year of the forecast period, based on this detailed vehicle activity data as well as data on vehicle characteristics and fuel characteristics.

5.2.1 The COPERT III methodology

The calculation of fuel consumption and emissions thus applies the COPERT III methodology[79].

COPERT III enables calculation of cold start and hot emissions of NO_x, VOC, CO and particulate matter (PM10). Evaporative VOC emissions are also computed. NO_x and VOC will enter in the formation of tropospheric ozone (O_3). However, assessing secondary pollutants such as ozone concentration is not within the scope of the TREMOVE model. Benzene (C_6H_6)is computed as a share of all non-methane VOC emissions. Methane emissions are thus also computed in TREMOVE. Emissions of CO_2, SO_2 and N_2O are also included in TREMOVE, following a much simpler methodology, as described in the COPERT III documentation.

CO_2 emissions are directly linked with the carbon content of the fuel. SO_2 emissions are directly proportional to the fuel consumption and the sulphur content of the fuel. For methane and N_2O, COPERT III provides emission factors that include all emissions. Additional cold start emissions are thus not taken into account separately, but are assumed to be included into the published emission factor.

The reader is referred to the COPERT III[80] methodology manual for further details.
Within the TREMOVE development, a number of additions have been brought to the COPERT III methodology to take account of developments that occurred since the publication of this methodology. The following section discusses the additions related to fuel consumption and CO_2 emission modelling. Thereafter an overview of the other revisions made to the COPERT III methodology will follow.

5.2.2 Extension of the COPERT III methodology : fuel consumption and CO_2 emissions

5.2.2.1 Overview

The COPERT III methodology provides an extensive set of fuel consumption functions for road transport. Though, for application in the TREMOVE model some refinements were added with respect to the following issues:

- The COPERT fuel consumption factors for diesel passenger cars are not differentiated for different engine sizes.

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79 COPERT = COmputer Program to calculate Emissions from Road Traffic, a computer program developed in the framework of the European Environment Agency's CORINAIR project).

80 Ntziachristos L. and Samaras Z. (2000), *Copert III Computer Programme to Calculate Emissions from Road Transport, Methodology and Emission Factors,* European Environment Agency

- Technological improvements over the recent years have lead to improved fuel efficiency however the fuel consumption functions in COPERT III do not reflect this evolution.
- Differences between COPERT III emission factors and real world behaviour may exist.
- TREMOVE needs fuel consumption factors for alternative technologies, being hybrid cars and CNG busses.

The fuel efficiency improvements for cars are resulting from a voluntary agreement between the European Commission and the car manufacturers (the so-called "ACEA-agreement")[81]. The commitment made by the European car manufacturers is to reduce CO_2 emissions to an average of 140 g/km for new cars sold by 2008.

5.2.2.2 Diesel car engine size differentiation

The COPERT III methodology provides one fuel efficiency factor for all diesel car engine sizes. As part of the EU strategy on CO_2 emissions from new passenger cars a data collection system was implemented[82]. From these statistics it can be observed that fuel consumption is clearly correlated with engine size.

In the context of TREMOVE, the year 2002 data for diesel cars have been aggregated assuming a fixed conversion rate between CO_2 emissions and fuel consumption of 3,069 ton CO_2 per toe. The calculated values for EU14 fuel consumption[83] can be found in the below table. Based on these figures coefficients have been calculated to apply to the COPERT III fuel consumption figures, as the ratio of the engine size specific consumption to the average value. The coefficients have been added to the table.

Table 44: New diesel cars test cycle fuel efficiency

engine size	< 1,4 l	1,4 l – 2,0 l	> 2,0 l	all
new car fuel efficiency in l/100 km (EU14 avg.)	4,20	5,50	7,60	5,90
fuel consumption coefficient	0,71	0,94	1,29	

As emissions of CO_2 and SO_2 are closely related to fuel consumption, emission factors for these emission factors have been corrected as well.

5.2.2.3 Fuel efficiency improvements for passenger cars

Three agreements have been made between the European Commission and the car manufacturers. The commitment of the manufacturers consists mainly in improving fuel efficiency by technological improvements to reach an average level of 140 g/km by 2009[84].

TREMOVE assumes these targets to be reached, although it should be noted that some doubt exists regarding the full implementation as no effective sanction at the individual manufacturer level has been determined.

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81 Three agreements have been made, the full texts can be found in the Official Journal of the European Communities L 350, 28. 12. 1998, 9 58; L 100, 20. 4. 2000, p. 57 and L 100, 20. 4. 2000, p. 55

82 The monitoring decision can be found in the Official Journal of the European Communities L 2020, 10. 8. 2000, p.1

83 No data for Ireland was available in the version of the database provided by the Commission.

84 To be correct, the target year is 2008 for ACEA and 2009 for JAMA and KAMA. In TREMOVE, we will assume one target year of 2009 for simplicity.

To allow implementing the ACEA-agreements evolution in TREMOVE, an assessment had to be made on some issues on which the agreement is not clear :

- How is the effort distributed over the countries, as the current levels differ over the countries it is probable that the target will not be reached in all countries (only the EU average target is set).
- No reference share of diesel vehicles has been recorded.

The first problem can be solved by assuming the relative effort to be the same for all countries.

The second issue is more difficult to tackle. In the reports monitoring the evolution of CO_2 emissions of new cars[85], the average CO_2 emission factor is used to evaluate the progress made by the manufacturers. The reduction in recent years is clearly partially a result of a shift from gasoline to diesel cars. It is not clear if this can be considered as being technological improvements : the agreements indicate that the reductions have to be realised by technical measures taken by the manufacturers[86].

Earlier research by COWI (2002) assumed the reduction target to be realised for both fuels separately. That would mean a 25 % reduction of fuel efficiency between 1995 and 2008. Above this improvement, a 2-3% CO_2 factor reduction is assumed as resulting from the introduction of 10 ppm sulphur fuels. Finally, a rebound effect[87] is expected by COWI, requiring an additional reduction of 1,7-2,9%. The overall reduction in the 1995-2008 period is estimated to amount to 28,7 % for diesel cars and 30,9 % for gasoline cars.

Plotkin (2001) follows a similar interpretation in fixing the reduction target at 25% assuming no change in fuel mix.

The assumptions made in past research seem to be a little bit too conservative and the resulting targets unrealistic to be met. Considering past research combined with recent evolutions, TREMOVE assumes the ACEA-agreements to be implemented as following:

- An identical relative effort for all engine size and fuels based on 2002 statistics
- 140 g/km target to be met based on the 2002 fuel shares
- Low sulphur effect as estimated by COWI (2002)[88]
- The effort in the 2002-2009 period is the same for all years.

In Table 45 we provide an overview of the assumed fuel efficiency evolution. The same relative

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85 A yearly report is issued as a result of the monitoring decision (see above), all reports are downloadable at website http://europa.eu.int/comm/environment/co2/co2_monitoring.htm – we will refer to them further on in the text as the “CO2 monitoring reports”.

86 The 2003 report by the Commission states on this issue: “In addition, as requested by Article 10 of Decision 1753/2000, the Communications for the intermediate target year (monitoring year 2003 for ACEAand JAMA, and 2004 for KAMA) will address questions related to the reasons for the observed reductions. It has to be thoroughly assessed whether reductions registered are due to technical measures by the manufacturers, or due to changes in consumer behaviour.”

87 Improved fuel efficiency is expected that improved fuel economy incites consumers to buy bigger cars, which in turn increases average CO_2 emissions.

88 The ACEA agreement makes reference to the introduction of fuels with improved fuel quality based on Directive 98/70/EC, requiring maximum sulphur levels of 50 ppm by 2005. The Directive has since been amended to lower sulphur contents further down to 10 ppm by 2009 the latest. This amendment (Directive 2003/17/EG) was made after the ACEA agreement, for this reason we understand it as being complementary.

reductions will be applied for all countries.

Table 45: ACEA agreements implementation assumptions (EU15 average)

	diesel	gasoline	average
2002 (CO_2 monitoring report figures)	155	172	165
2009 target	132	146	140
2002-2009 evolution	-15,2%	-15,2%	-15,2%
Additional reduction by introducing low sulphur fuels	-2,0%	-3,0%	
Total reduction in the 2003-2009 period	*-17,2%*	*-18,2%*	
Annual reduction	-2,7%	-2,8%	

TREMOVE assumes no further fuel efficiency improvements after 2009[89]. For the 1995-2002 period, assumptions regarding the evolution of the fuel efficiency have been derived from the figures in the CO_2 monitoring reports (covering the 1995-2002 period). Furthermore, TREMOVE includes no significant fuel efficiency improvements between 1995 and 1990 cars and a yearly 1% fuel efficiency improvement for pre-1990 cars.

Emissions closely related to fuel consumption as indicated by COPERT III will evolve analogously in TREMOVE.

5.2.2.4 Fuel efficiency improvements for other road vehicles

In COPERT III, no improvements in fuel efficiency are included after the introduction of EURO I vehicles (mid-nineties). In the TREMOVE 2.2 baseline scenario fuel efficiency improvements for trucks, buses/coaches and motorcycles/mopeds have been added to the COPERT III fuel consumption factors for vehicles sold after 1996. The improvement rates for the 1997-2009 period (Table 47) are equal to the rates used in the Auto-Oil II program[90], which followed from discussions with ACEA. TREMOVE assumes no further fuel efficiency improvements after 2009.

Table 20: Fuel efficiency improvements for non car road vehicles

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
light duty vehicles	0,65%	0,65%	0,65%	0,65%	0,65%	0,65%	0,65%	1,75%	1,75%	1,75%	1,75%	1,75%	0,50%
heavy duty vehicles	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	0,50%
motorcycles and mopeds	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	1,00%	0,50%

5.2.2.5 Real world behaviour

So far we only discussed evolution of fuel efficiency over time and engine size classes. However, a tougher issue needed to be addressed: the difference between measured test cycle fuel consumption and fuel efficiency in real world conditions.

[89] This baseline assumption is needed to enable the assessment of the effects of further agreements with the car industry (the current voluntary agreement includes an option to discuss further reductions up to 120g CO_2/km on the longer term.

[90] European Commission, Standard & Poors' DRI, K.U.Leuven. *The AOP II Cost – Effectiveness Study.* August 1999.

The COPERT III methodology (Ntziachristos and Samaras, 2000)[91] is assumed to reflect real world conditions. However, for fuel consumption, the functions have been developed in the framework of older COPERT exercises. As for the reference year, no clear statement is made.

The authors of the COPERT III methodology seem to recognize somehow the problems that may result from the rather rough fuel consumption factors, and provide a methodology to bring calculated fuel consumption in line with statistics (e.g. energy balances). The application of this calculation based on TREMOVE modelling results should allow the estimation of the real world versus test cycle ratio – be it one ratio for all road technologies using the same fuel. This approach doesn't seem to contribute much refinement and may be more appropriate for validation of results.

Van den Brink and Van Wee (2001) provide figures regarding real world fuel consumption as compared to test cycle measurements. The real world consumption for the average new 1997 gasoline car is reported to be 10% higher than Eurotest (93/116/EC) figures. For Germany, the difference would amount to 17%. The authors expect the difference to increase due to the introduction of direct injection gasoline cars and the increasing share of airco-equipped cars in new sales. We assume the difference between test cycle and real world to amount to about 15%. We keep this difference constant over time as we have no evidence regarding a possible evolution[92].

In order to calculate a coefficient to apply to the COPERT III fuel consumption functions, COPERT functions were used to calculate fuel consumption. The COPERT functions calculate hot fuel consumption based on mileage shares and average speed for urban, rural and highway, and cold start fuel consumption based on average temperature and average trip length. For these calculations average trip lengths have been taken from average temperatures from Cox and Hickman (1998)[93]. For average speed and mileage shares we used the figures provided by Ntziachristos and Samaras (2000)[94]. Calculations have been made for eleven countries (EU12 minus Ireland because of data availability limitations), EU11 averages are shown in Table 46.

Table 46: 2002 average EU11 fuel consumption in l/100km

Fuel	*Diesel*	*Gasoline*
Test cycle measurements result (CO_2 monitoring database)	5,9	7,5
COPERT III simulated efficiency	6,2	7,6
Difference	5,4%	1,6%

The COPERT III methodology seems to be below the assumed 15% difference for 2002. Therefore it was decided to change the COPERT III functions for 2002 by introducing a coefficient with value 1,1. This results in a difference between COPERT based simulations and test cycle measurements of 15,9% (diesel) and 11,8% (gasoline) for 2002.

[91] Ntziachristos L., Samaras Z. *Copert III computer programme to calculate emission factors from road transport. Modelling and emission factors (version 2.1.).* Report to the European Environment Agency, 2000.

[92] To be correct, we assume a small increase resulting from the changed test cycle specification applying from 2001 on; however the difference between both test cycle CO2 emissions is expected to amount to 0,7% according to the most recent CO2 monitoring report by the Commission.

[93] Hickman J., Hassel, D., Joumard, R., Samaras, Z., Sorenson, S. (1999) Methodology for calculating transport emissions and energy consumption, TRL, Crowthorne (Downloadable from website http://www.inrets.fr/infos/cost319/M22.pdf).

[94] These figures were based on earlier COPERT research.

The evolution over time and engine size classes, set out in paragraphs 5.2.2.2 and 5.2.2.3, then has been applied using 2002 as a reference year. The 1,1 coefficient has not been applied to the COPERT function for pre-EURO I cars.

5.2.2.6 Fuel consumption for alternative technologies : hybrid cars and CNG buses

TREMOVE 2.2 includes CNG buses as well as parallel (or combined) hybrid technologies both for diesel and gasoline cars, and for all size classes. Neither for the CNG vehicles nor the hybrid vehicles, fuel consumption factors are readily available within COPERT III. Therefore following assumptions have been included in the model :

- Hybrid fuel efficiency: a reduction of 20% for diesel hybrid cars and 30% for gasoline hybrid cars compared to conventional combustion engine vehicles
- CNG buses have same energetic fuel efficiency as conventional EURO II buses

5.2.3 Extension of the COPERT III methodology: influence of fuel specifications and update of moped and motorcycle emission factors

5.2.3.1 Impact of fuel specifications

The impact of changes in fuel specifications on vehicle emissions have been taken into account by introducing the EPEFE equations, developed within the Auto-Oil I program[95].

5.2.3.2 Update of motorcycle and moped emission factors

The COPERT III methodology does not provide emission factors for 2-wheelers complying to the most recent emission standards (EURO II, EURO III). In fact, the available motorcycle and moped emission factors in COPERT are based on relative old measurements. Therefore, the COPERT moped and motorcycle emission factors have been updated using information provided by the University of Thessaloniki, Laboratory of Applied Thermodynamics. They provided information drawn from their measurement work related to their impact assessment of new requirements relating to the emissions from two and three-wheel motor vehicles performed for the European Commission[96].

5.2.3.3 Emissions of alternative technologies: hybrid cars and CNG buses

TREMOVE 2.2 includes CNG buses as well as parallel (or combined) hybrid technologies both for diesel and gasoline cars, and for all size classes. Neither for the CNG vehicles nor the hybrid vehicles, emission factors are readily available within COPERT III. Therefore following extensions to COPERT III have been included in the model :

5.2.3.3.1 CNG buses

The methodology for CNG bus emission calculations have been derived from MEET[97]. MEET proposes adjustment factors that are to be applied to convert nowadays diesel bus hot and cold

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95 ACEA and EUROPIA. (1996) *European Programme on Emissions, Fuels and Engine Technologies,* Final Report.

96 Dr. Leonidas Ntziachristos, Athanasios Mamakos, Anastastios Xanthopoulos, Prof. Eleytherios Iakovou. (June 2004). Impact assessment/Package of New Requirements Relating to the Emissions from Two and Three-Wheel Motor Vehicles. Final Report to the European Commission, Directorate Enterprise.

97 Meet, 1999.

emission factors to emission factors for CNG buses. These adjustment factors are available for CO, NOx, VOC and PM and were applied to the COPERT EURO II diesel bus emission factors.

Table 22: Adjustment factors for CNG bus emission factors (MEET)

PM	0.085
NOx	0.583
VOC	3.380
CO	0.464

Estimation of CO_2 emission factors from fuel consumption factors has been performed using carbon balance calculations[98]. Similarly SO_2 emission factors were set to zero, given the negligible sulphur content of CNG. Furthermore TREMOVE assumes all VOC emissions to be CH_4.

With respect to N_2O, no specific information on CNG bus emission factors has been found. Emission factors for CNG buses is approximated by using the emission factor for EURO II diesel buses.

5.2.3.3.2 Hybrid cars

As indicated earlier, a reduction of 20% for diesel hybrid cars and 30% for gasoline hybrid cars compared to conventional combustion engine vehicles is included for fuel consumption and related emissions (i.e. CO_2 and SO_2).

For the remaining pollutants TREMOVE uses identical emission factors for the hybrid cars and their conventional counterparts. This assumption could be supported by the fact that there is no legal incentive for car manufacturers to produce hybrid vehicles that would reduce emissions further than the emission standard requirements. Furthermore, introducing technologies that would overcomply to EURO IV standards would of limit the capability of TREMOVE to assess the full effect of proposals for the EURO V standards

5.3 Train transport emissions

The concern with emissions from trains is only around ten years old, so the results of detailed emission calculations are quite limited.

As ARTEMIS emission factors are not yet available, TREMOVE applies average emission factors for the diesel train types (in gram per vkm) derived from the energy consumption and emission factors that were used in the TRENDS project. These averaged emission factors are available for CO, CO_2, VOC, NO_x, PM and SO_2.. For electric trains only energy consumption is calculated in the fuel consumption and emission module. Emissions related to the generation of the electricity in power plants are calculated in the lifecycle module.

For each year the TREMOVE vehicle stock module produces figures on the vehicle-kilometres for train transport disaggregated to:

- Vehicle type
- Fuel type (diesel or electric)

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98 CO_2 [ton] = FC [ton] * 44,011 / (12,011 + 1,008*RHC), where RHC is hydrogen-to-carbon ratio (1,6 for kerosene; 1,8 for gasoline, 2,0 for diesel; ~4 for CNG).

- Vehicle technology
- Vehicle age (age and technology are related to each other)
- Trip distance (urban, short distance, long distance)
- Model region (metropolitan, other cities, non urban)
- Period of day (peak or off-peak)

The emission module then calculates fuel/energy consumption and vehicle emissions for each year of the 1995-2020 period. As the TREMOVE 2.2 model applies average emission factors for each train and technology type, it does not make fully use of the level of detail at which the vehicle stock module operates (i.e. differences between service type, train vintages, etc. are not taken into consideration in the current train emission module).

5.3.1 Train emission and energy consumption factors in TREMOVE 2.2

For diesel trains, the averaged emission factors by train type are derived directly from the 1995 TRENDS figures. For each country and each train type an average emission factor was computed by dividing 1995 emissions (in gram per year) by 1995 train-kilometres (in km per year) in the TRENDS database. The 1995 average emission factors that are derived from TRENDS in this way are applied to the whole 1995-2020 period within TREMOVE 2.2. It should be noted that the average emission factors differ between countries, amongst others due to differences in vehicle weight and vehicle usage that are incorporated in the TRENDS figures.

Estimates for electricity consumption of electric trains have been estimated based on TRENDS information and assumptions on train vehicle weights.

By way of example, Table 47 shows the averaged emission factors used for France within TREMOVE 2.2.

Table 47: TREMOVE 2.2 emission and energy consumption factors for trains in France

			Emission factors in g/trainkm						**g/kWh**
			CO	CO_2	VOC	NO_x	PM	SO_2	kWh
Freight	Locomotive	Diesel	42,0	12505,8	11,8	221,8	13,4	15,1	
Freight	Locomotive	Electric							25 (long dist.)
(Freight)	(Railcar)	(Electric)							(20) (short dist)
Passenger	Locomotive	Diesel	21,3	6336,0	6,0	112,4	6,8	7,7	
Passenger	Locomotive	Electric							8
Passenger	Railcar	Diesel	20,1	5992,8	5,6	106,3	6,4	7,2	
Passenger	Railcar	Electric							12.5
Passenger	High Speed Train	Electric							15

The TRENDS emission calculations, from which the TREMOVE 2.2 emission factors have been derived, have been based on the outcomes of the MEET project and additional data supplied by railway companies to the TRENDS project. The method applied in TRENDS is to calculate emissions from energy or fuel consumption, using energy specific emission factors (g/kW.h or g/kg of fuel). The first step in the calculation procedure is the estimation of the energy consumption of a given type of train in kJ per ton-km. Secondly, pollutant emissions are calculated from the energy and/or fuel used using energy specific emission factors. The procedure applies to diesel and electric trains, but in the latter case, the emission factors relate to the production of the electricity rather than the combustion of fuel in the locomotive. The reader is referred to the TRENDS[99] documentation for further details.

5.3.2 Envisaged update of the train energy consumption and emissions module

Although the ARTEMIS project will not be finalised in the short term, the TREMOVE project team has good hopes that, with respect to rail transport, intermediate results of the ARTEMIS project will become available. The project team therefore intends to improve the energy consumption and emission factors in TREMOVE 2.2 to the extent possible, making use of preliminary ARTEMIS[100] outcomes. In this context, it will be studied also whether it is feasible to make better use of the level of detail at which the vehicle stock module operates, instead of using average emission factors per train type.

Furthermore, it is intended to include in the model the improvements in environmental performances of trains that are enforced by Directive 97/68 and the recent amendment to this Directive (stages IIIa and IIIb).

5.4 Tram and metro energy consumption

For tram and metro, the vehicle stocks are not explicitly modelled. Emissions and energy consumption are calculated directly from passenger-km data, by applying observed German and Swiss occupancy rates and estimated average energy consumption factors.

The current TREMOVE 2.2 model uses following energy consumption factors for trams and metros throughout the 1995 – 2020 period.

- Metro: 2,5 kWh / vehicle-km
- Tram: 4,0 kWh / vehicle-km

Furthermore, the indirect emissions due to energy production in power plants are assessed in the life cycle emission module.

5.5 Inland waterway emissions

Fuel consumption in gram per year and emissions in gram per year are calculated by multiplying vkm by ship type by a fuel consumption or emission factor, both in gram per vkm.

These factors are calculated following (the first version of the) approach developed within ARTEMIS by the Danish Technical University[101] in an Excel macro supplied by DTU to the TREMOVE modellers. By calculating the resistance (friction and other) on the vessels, the needed engine power and fuel consumption is estimated. Emission factors then are derived from calculated fuel consumption and information on fuel characteristics. The fuel is assumed to be gasoil and contain

[99] Georgakaki Aliki, Coffey R., Sorenson S.C. (2002) *Transport and Environment Database System (TRENDS) . Detailed Report 3 : Railway Module* Project funded by the European Commission – Directorate General for Transport and Energy

[100] ARTEMIS website: *http://www.trl.co.uk/artemis/*

[101] Georgakaki A. (2003), ARTEMIS approach Version 1, *Energy consumption and Air Pollutant emissions from rail and maritime transport. Focus on inland shipping*, PhD thesis, promoter Spencer C. Sorensen DTU, Denmark

0,2% sulphur. The macro estimates emission factors for: CO, VOC, NO_x, PM, SO_2, CO_2, N_2O, CH_4, NMVOC.

5.5.1 Assumptions

In order to be able to use the preliminary ARTEMIS calculation tool, some assumptions had to be made on both vessel characteristics as vessel usage.

TREMOVE considers 21 ship types. These had to be linked to ship types, for which there is the necessary ship characteristic data to calculate emission factors. The linkage was done as follows :

Table 48: Ship types in TREMOVE

TREMOVE weight class / vessel type	Tanker Vessel	Pusher Craft	Dry Cargo Vessel
< 250 tonnes	Spits	Combination of a motorised GMS ship and one Europe II barge (in straight line)	Spits
250 – 400 tonnes	Spits		Spits
400- 650 tonnes	Kempenaar		Kempenaar
650 – 1000 tonnes	DEK/ G.Koenings		DEK/ G.Koenings
1000 – 1500 tonnes	RHK		RHK
1500 – 3000 tonnes	Tank Ship		GMS
>3000 tonnes	Tank Ship	Combination of motorized pusher ship and 4 push barges (in 2*2 formation)	GMS

Furthermore, following data and assumptions were used to produce the emission and fuel consumption factors:

Table 49: Characteristics per ship type

Ship type	Ship length (m)	Length between perpendiculars	Ship breadth	Ship draught	Fraction of load draught (~load factor)	Maximum load weight (ton)
Cargo < 250 tonnes	38,7	38,17	5,05	2,2	0,6	364
Cargo 250-400 tonnes	38,7	38,17	5,05	2,2	0,6	364
Cargo 400 – 650 tonnes	50	49,31	6,6	2,5	0,55	638
Cargo 650 – 1000 tonnes	67	66,08	8,2	2,5	0,55	968
Cargo 1000 – 1500 tonnes	80	78,90	9,5	2,5	0,55	1.350
Cargo 1500 – 3000 tonnes	105	103,55	9,5	3,2	0,55	2.160
Cargo > 3000 tonnes	105	103,55	9,5	3,2	0,55	2.160
Tanker < 250 tonnes	38,7	38,17	5,05	2,2	0,6	364
Tanker 250-400 tonnes	38,7	38,17	5,05	2,2	0,6	364
Tanker 400 – 650 tonnes	50	49,31	6,6	2,5	0,55	638
Tanker 650 – 1000 tonnes	67	66,08	8,2	2,5	0,55	968
Tanker 1000 – 1500 tonnes	80	78,90	9,5	2,5	0,55	1.350
Tanker 1500 – 3000 tonnes	110	108,49	11,4	3,5	0,55	3.000
Tanker > 3000 tonnes	110	108,49	11,4	3,5	0,55	3.000
Pusher < 3000 tonnes	185	182,45	11,40	2,50	1,00	4.000
Pusher > 3000 tonnes	190	187,38	22,8	2,5	1,00	7.700

Speed of all vessels was assumed to be 10 km/h (relative to water speed).

5.5.2 Fuel consumption and emission factors in TREMOVE 2.2

Applying the preliminary ARTEMIS methodology, including the assumptions from the previous section, results in the following fuel consumption and emission factors in TREMOVE 2.2.

Table 50: Fuel consumption factor in g fuel per vkm for motorised ships

Cargo < 250 tonnes	972,9167
Cargo 250-400 tonnes	972,9167
Cargo 400 – 650 tonnes	1360,383
Cargo 650 – 1000 tonnes	2030,117
Cargo 1000 – 1500 tonnes	2779,778
Cargo 1500 – 3000 tonnes	5058,456
Cargo > 3000 tonnes	5058,456
Tanker < 250 tonnes	972,9167
Tanker 250-400 tonnes	972,9167
Tanker 400 – 650 tonnes	1360,383
Tanker 650 – 1000 tonnes	2030,117
Tanker 1000 – 1500 tonnes	2779,778
Tanker 1500 – 3000 tonnes	7876,768
Cargo < 250 tonnes	7876,768

Table 51: Emission factors in g per vkm

	CO	VOC	NO_x	PM	SO_2	CO_2	N_2O	CH_4	NMVOC
Cargo < 250 tonnes	3	3	58	4	3	3045	1	0	3
Cargo 250-400 tonnes	3	3	58	4	3	3045	1	0	3
Cargo 400 – 650 tonnes	4	4	82	5	5	4258	1	0	4
Cargo 650 – 1000 tonnes	6	6	122	8	7	6354	1	0	6
Cargo 1000 – 1500 tonnes	8	8	167	11	9	8701	2	0	8
Cargo 1500 – 3000 tonnes	15	15	304	20	17	15833	3	1	14
Cargo > 3000 tonnes	15	15	304	20	17	15833	3	1	14
Tanker < 250 tonnes	3	3	58	4	3	3045	1	0	3
Tanker 250-400 tonnes	3	3	58	4	3	3045	1	0	3
Tanker 400 – 650 tonnes	4	4	82	5	5	4258	1	0	4
Tanker 650 – 1000 tonnes	6	6	122	8	7	6354	1	0	6
Tanker 1000 – 1500 tonnes	8	8	167	11	9	8701	2	0	8
Tanker 1500 – 3000 tonnes	24	24	473	32	27	24654	5	1	23
Cargo < 250 tonnes	24	24	473	32	27	24654	5	1	23

Table 52: Fuel consumption factor in g fuel per vkm for pushers and barge combinations

Pusher < 3000 tonnes	6618,459
Pusher > 3000 tonnes	13685,29

Table 53: Emission factors in g per vkm for pushers and barge combinations

	CO	VOC	NO_x	PM	SO_2	CO_2	N_2O	CH4	NMVOC
Pusher < 3000 tonnes	20	20	397	26	23	20716	5	1	19
Pusher > 3000 tonnes	41	41	821	55	47	42835	9	2	39

These fuel consumption and emission factors are used throughout the 1995 to 2020 period.

5.6 Air transport emissions

Emissions (CO_2, NO_x , CO and VOC) and fuel consumption for planes are directly computed from the demand module with emission factors. Fuel consumption and emissions for each distance class (<500km, 500-1000 km, 1000-1500 km, 1500-2000 km , >2000 km) are calculated by multiplying pkm from the demand module by an appropriate estimated fuel consumption or emission factor (in g per pkm, for each distance class).

Figures on total (fuel consumption and) emissions and seat-km by distance class were obtained from the AVIOPOLL database[102], which has been constructed in the TRENDS project[103][104]. The database refers to 2000 and contains total emission and seat-km data on some 8,4 million flights. The number of seat-km was recalculated to passenger-km assuming an overall occupancy rate of 70%[105]. Appropriate (fuel consumption and) emission factors for use in TREMOVE 2.2 then were calculated by dividing the AVIOPOLL total of (fuel consumption or) emissions by the total AVIOPOLL passenger-km for the distance class under consideration.

The following average emission factors were calculated and are used for the 1995- 2020 period:

Table 54: Emission factors for air transport

Distance class	Fuel consumption and emission factor for air (g/passenger-km)			
	Fuel consumption	NO_x	VOC	CO
0-500	76,210	1,043	0,0706	0,372
500-1000	57,087	0,632	0,0551	0,224
1000-1500	42,978	0,429	0,0377	0,141
1500-2000	41,376	0,389	0,0372	0,118
>2000	42,927	0,393	0,0284	0,069

Estimation of CO_2 emission factors from fuel consumption factors has been performed using carbon balance calculations[106].

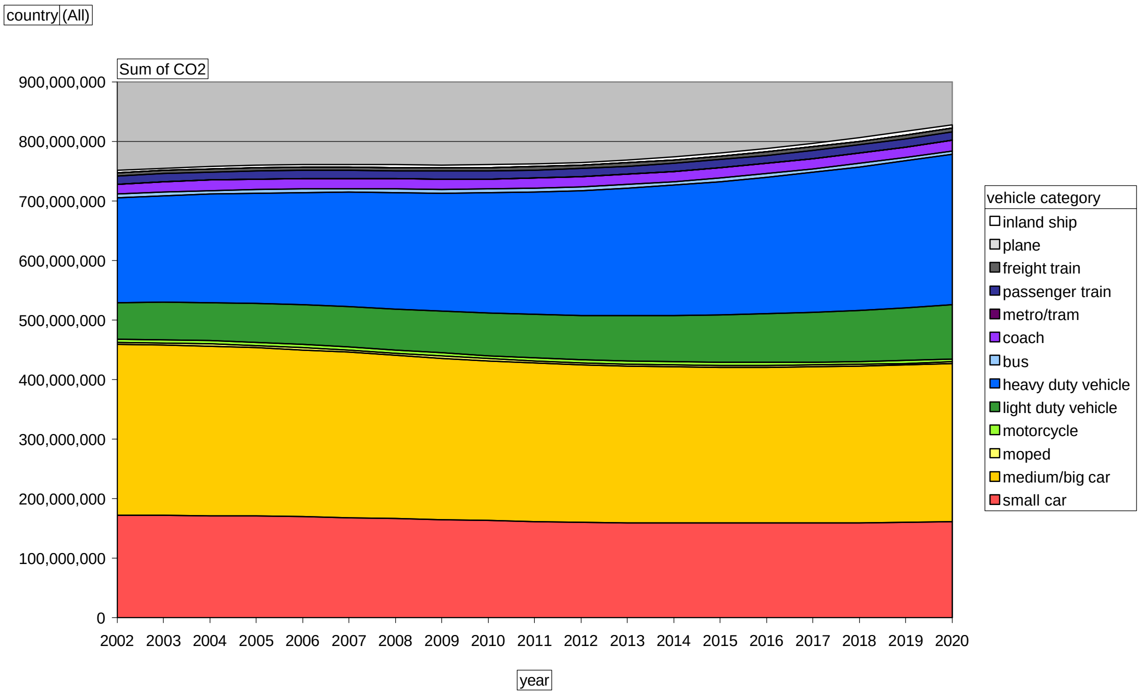
[102] No links with the AERONET or AERO-II-K programs have been established. http://www.aero-net.org
[103] pSIA-Consult (2002) *Transport and Environment Database System (TRENDS) . Detailed Report 4 : Aviation Module* Project funded by the European Commission – Directorate General for Transport and Energy
[104] Given the delays in the ARTEMIS project, no ARTEMIS emission calculation methodology is available.
[105] Source: TRENDS.
[106] CO2 [ton] = FC [ton] * 44,011 / (12,011 + 1,008*RHC), where RHC is hydrogen-to-carbon ratio (1,6 for kerosene; 1,8 for gasoline, 2,0 for diesel).

5.7 Overview of the baseline results

5.7.1 Overview of CO_2 emissions

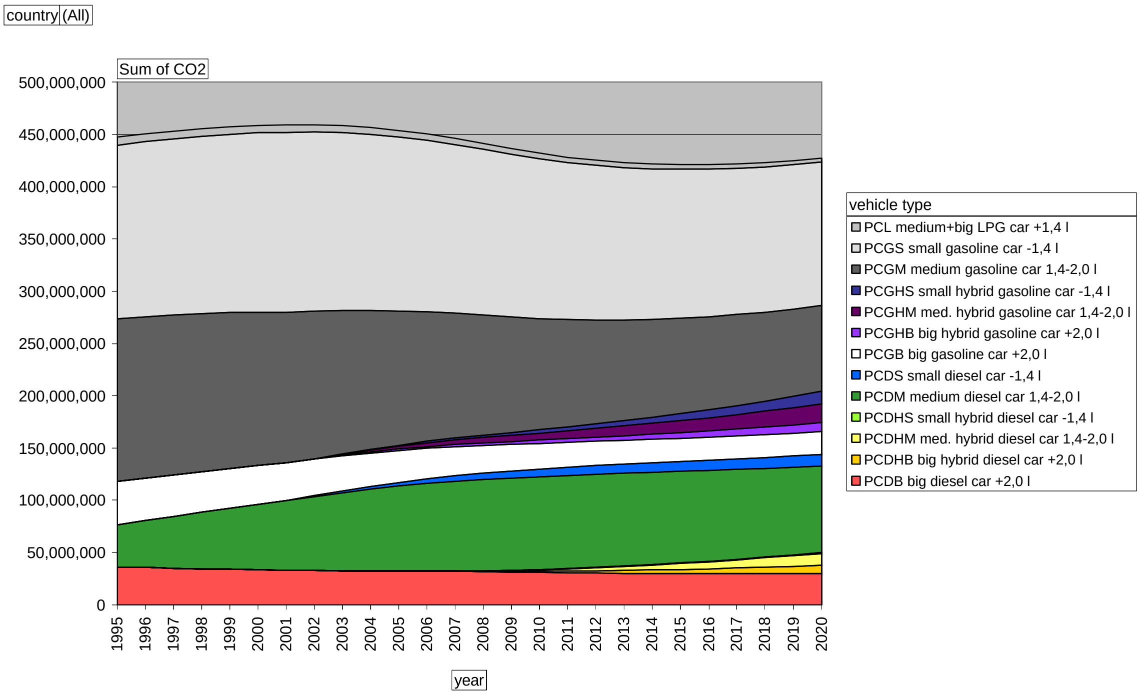
The figure below gives an overview of the CO_2 emissions for road transport in EU15. The total amount passenger cars is expected to have a more or less stable emission quantity (see Figure 20). Growth is mainly due to heavy duty vehicles.

Figure 19: CO_2 emissions in EU15 for all modes (except electric)



The figure below gives the CO_2 emissions for passenger cars in EU15. Total emission rise and ten drop again, due to an increase of car passenger traffic, penetration of diesels and a better fuel efficiency.

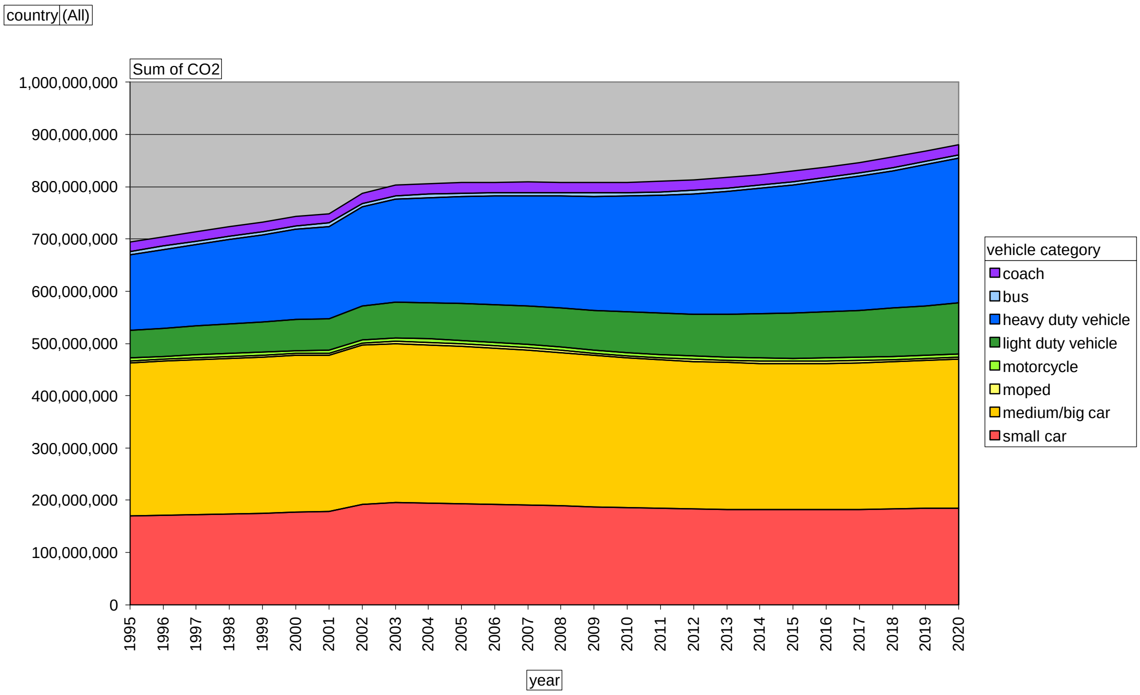
Figure 20: CO_2 emissions in EU15 for passenger cars



The next figure gives the same results for EU15 + NO, CH + CZ, HU, PL, SI.

The road vehicle stock model for the new Member States does not start from 1995, but from 2000 (SI), 2002 (HU and PL) and 2003 (CZ). Therefore, a little bump can be notified in the total emissions.

Figure 21: CO_2 emissions in all 21 modelled countries for road vehicles



The tables below show the same results for 3 separate countries: France, Germany and Poland.

Figure 22: CO_2 emissions in France for all modes (except electric)

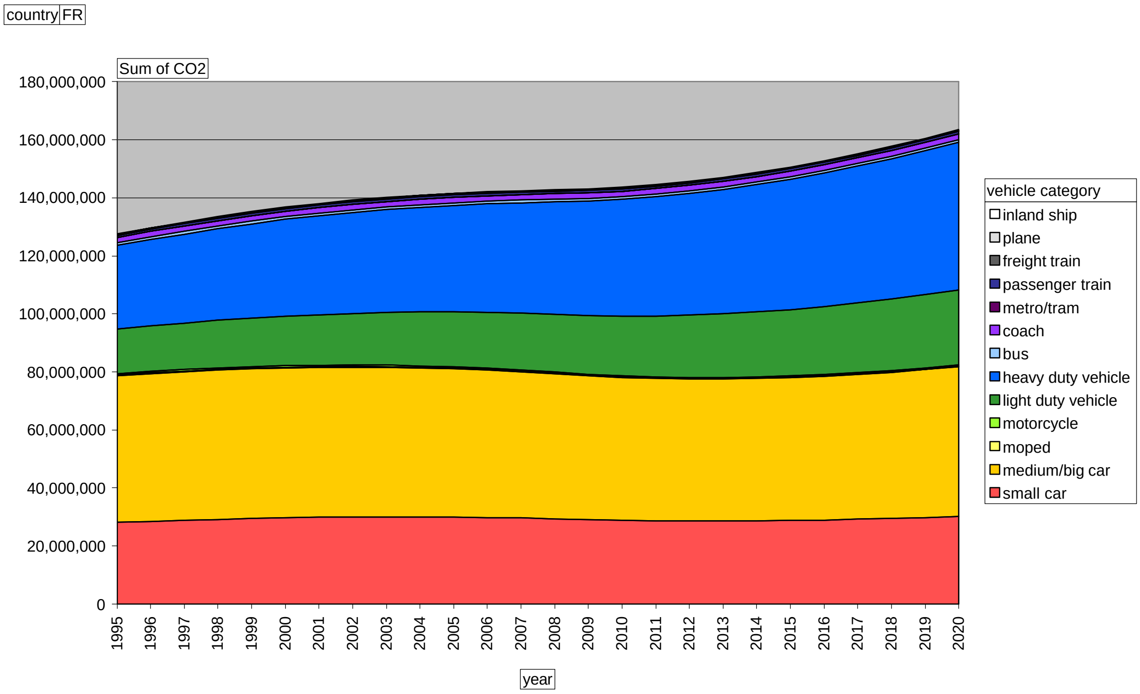


Figure 23: CO_2 emissions in France for passenger cars

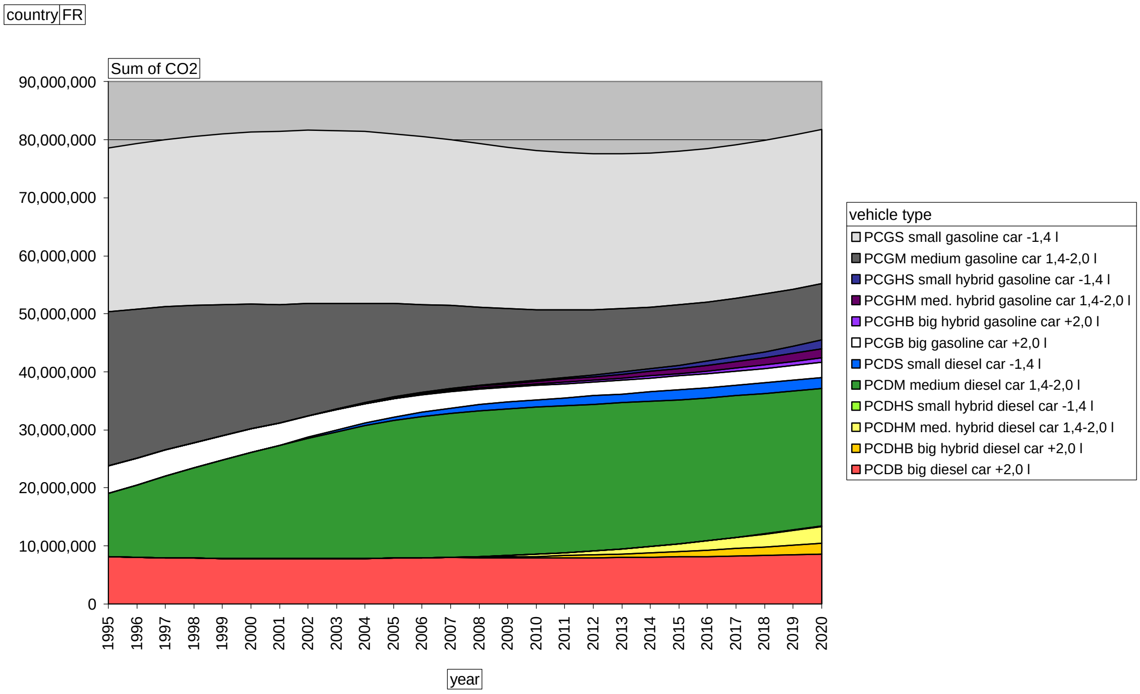


Figure 24: CO_2 emissions in Germany for all modes (except electric)

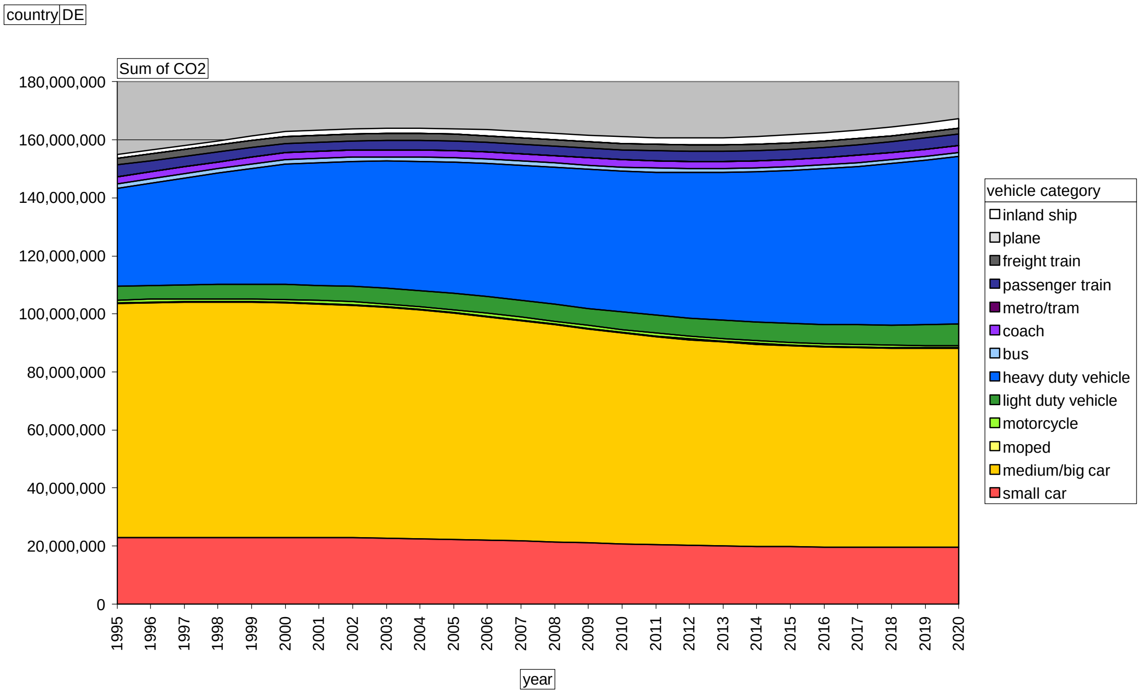


Figure 25: CO_2 emissions in Germany for passenger cars

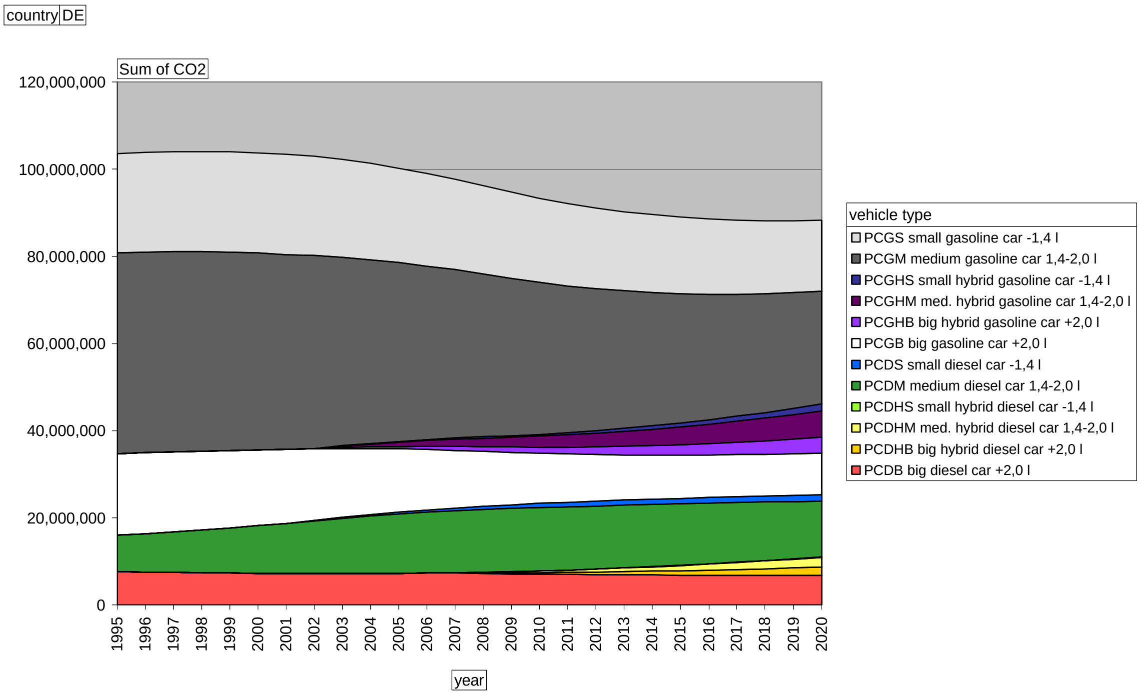
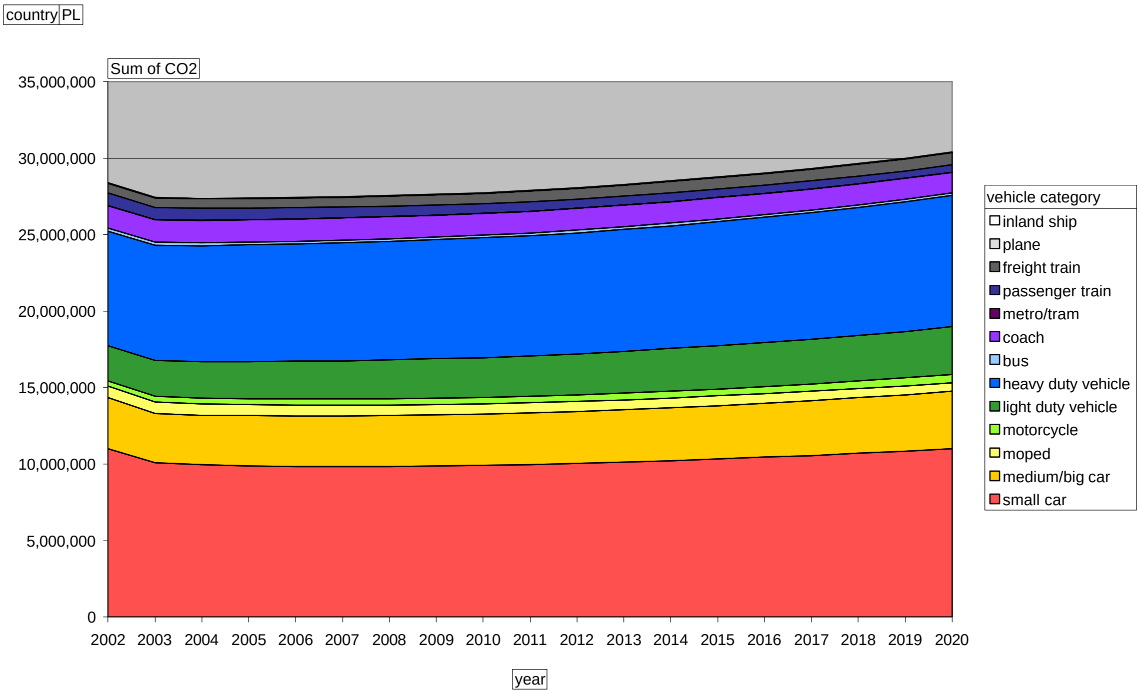
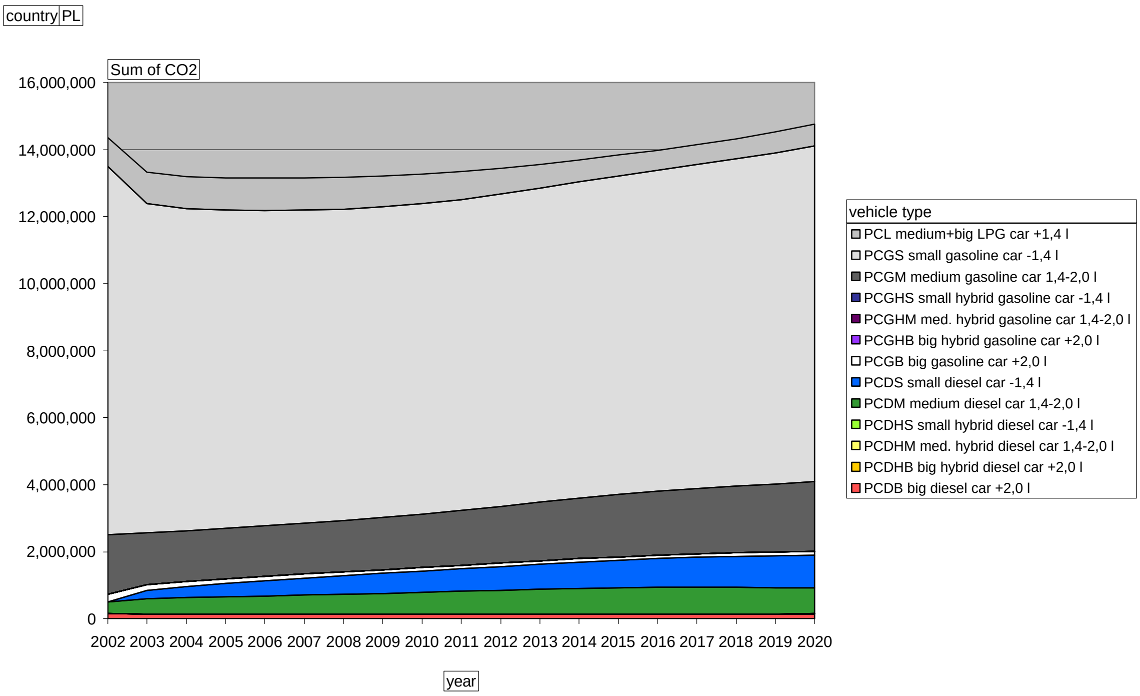


Figure 26: CO_2 emissions in Poland for all modes (except electric)



Note: the PL model only starts in 2002.

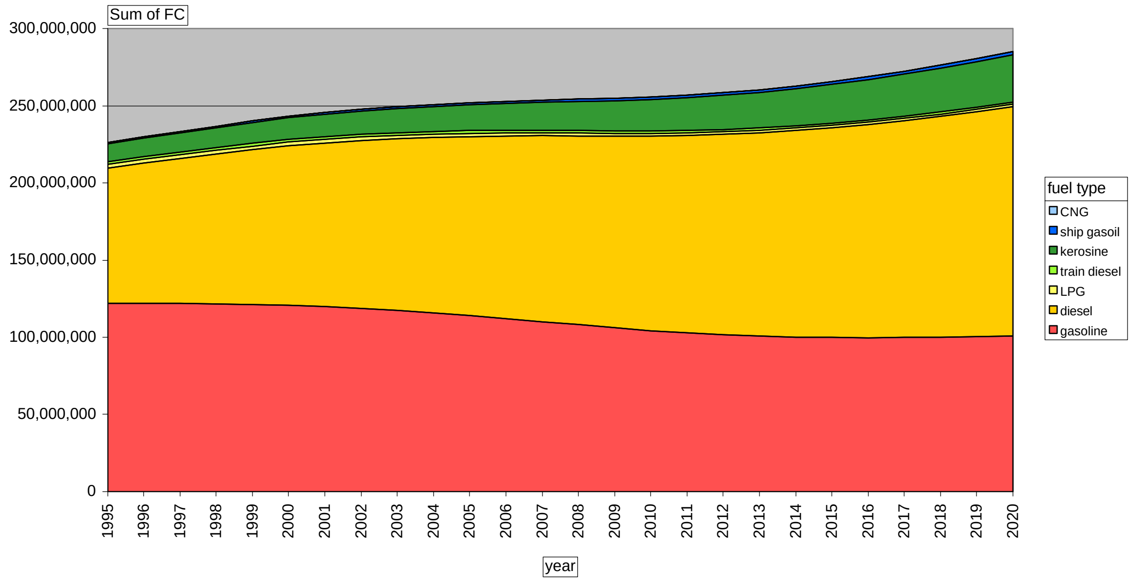
Figure 27: CO_2 emissions in Poland for passenger cars



5.7.2 *Fuel consumption*

The figure below gives an overview of the fuel consumption in EU15 per fuel type.

Figure 28: EU15 total fuel consumption in tonnes.



The table below shows a comparison of the apparent fuel consumption factors[107] (only oil technologies, no electric trains or trams) per country. The fuel consumption per vkm, pkm and tkm in the EU15 countries is fairly equal.

In the "poorer" countries in the community, ie Ireland, Greece and Portugal a relatively lower fuel consumption per vkm can be found. This is a logic result given the larger share of smaller cars/mopeds/bus in those countries.

Similar tables can be made for e.g. PM, CO etc, for other years and for the remaining 6 countries. We refer the reader to the TREMOVE baseline database.

Table 55: TREMOVE apparent fuel consumption factors for all EU15 countries in 2000

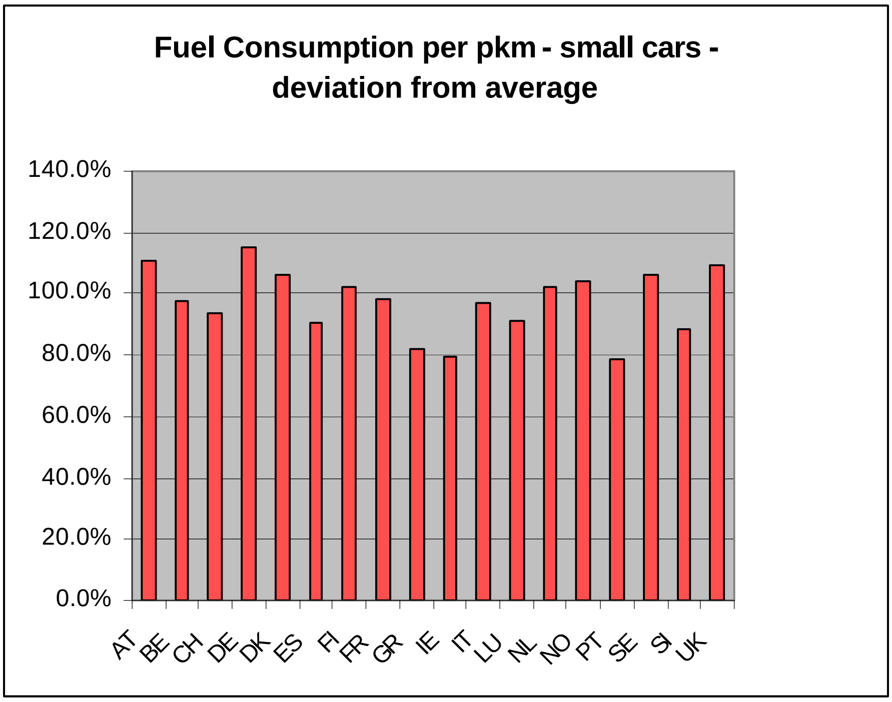
	vehicle category	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	Grand Total
FC	small car	885.775	700.891	7.211.915	1.188.423	4.709.687	1.028.992	9.321.646	1.692.510	598.207	12.470.701	52.683	2.304.591	1.296.285	950.261	9.461.629	55.719.477
	medium/big car	2.003.362	3.209.485	25.468.422	1.226.907	5.299.758	1.137.557	16.354.594	571.547	379.241	10.740.502	122.220	3.545.627	1.244.644	2.935.054	16.547.588	94.720.694
	moped	20.152	14.406	79.156	3.917	153.538	6.207	90.039	142.018	2.418	706.244	570	21.104	78.850	5.852	15.346	1.395.729
	motorcycle	25.976	25.573	296.919	6.018	203.285	16.186	146.865	224.298	5.199	535.370	996	41.355	32.083	9.329	100.716	1.746.336
	light duty vehicle	36.879	415.242	1.635.136	213.760	3.001.122	484.551	5.432.182	447.192	59.726	2.078.510	9.975	10.343	139.839	616.240	4.023.286	18.862.370
	heavy duty vehicle	917.495	1.397.389	13.235.688	625.004	5.827.990	1.226.900	10.631.230	756.430	269.369	9.399.836	90.642	1.649.361	647.073	1.311.467	5.836.485	55.032.021
	bus	44.759	35.437	459.142	90.338	170.450	41.477	301.758	112.313	31.980	285.068	6.294	41.021	26.068	74.326	328.067	2.100.486
	coach	159.233	207.990	784.186	122.513	526.461	114.689	592.991	316.019	76.882	1.536.302	8.955	179.718	161.115	144.007	557.907	5.652.691
	passenger train	12.791	8.250	224.181	91.177	69.122	9.583	145.182	54.955	12.485	67.175	854	29.560	16.922	10.171	483.647	1.455.054
	freight train	22.346	19.172	142.569	18.277	35.799	41.002	77.128	3.597	8.490	9.540	2.439	6.685	18.875	12.743	136.791	664.847
	plane	658.054	2.097.214	2.420.120	131.741	871.876	504.281	1.075.184	360.805	209.385	918.128	482.076	487.580	145.416	873.139	2.533.760	15.175.673

107 "Apparent", because in the model the fuel consumption has been calculated in a very detailed way. These "factors" are the result of dividing the total fuel consumption by the total number of km driven.

	vehicle category	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	Grand Total
	inland ship	23.859	76.953	543.286				56.226					417.627				1.140.043
FC/vkm	small car	66,81	64,28	66,65	64,77	64,02	66,93	64,09	68,46	63,73	65,75	57,75	63,81	65,90	64,51	61,86	64,63
	medium/big car	76,51	71,93	80,45	81,33	72,55	81,87	72,97	80,32	77,44	72,60	66,21	74,35	78,55	77,11	75,77	76,07
	moped	23,78	23,39	24,03	20,70	22,76	19,83	19,04	23,84	20,28	22,89	22,11	22,06	22,79	22,21	19,44	22,60
	motorcycle	36,32	35,10	33,79	31,38	30,31	28,94	19,86	31,32	28,12	20,90	30,27	32,39	23,46	30,19	29,70	26,21
	light duty vehicle	83,24	79,69	82,12	93,45	88,46	90,07	84,42	94,88	87,58	87,43	89,70	95,52	87,70	99,08	89,88	87,26
	heavy duty vehicle	254,56	285,09	299,19	254,95	281,29	275,29	284,03	270,29	253,42	296,89	263,93	277,12	311,73	277,29	264,23	285,05
	bus	286,82	280,06	280,97	283,95	294,43	283,93	283,38	308,33	297,02	283,25	261,82	281,05	304,50	275,91	276,50	283,64
	coach	279,70	272,62	259,78	293,15	288,46	296,75	268,11	306,19	289,68	297,81	264,90	290,01	280,86	288,23	261,37	281,46
	passenger train	693	222	6.954	2.649	1.512	247	4.230	14.589	1.103	2.679	40	705	657	203	7.687,14	2.220,22
	freight train	2.744	1.929	14.761	856	4.447	3.375	8.742	3.044	1.832	1.290	417	418	2.228	1.707	8.207,37	3.379,11
	inland ship	3.912	3.158	3.521				3.189					3.354				3.405,70
FC/vkm %	small car	103,4%	99,5%	103,1%	100,2%	99,1%	103,6%	99,2%	105,9%	98,6%	101,7%	89,4%	98,7%	102,0%	99,8%	95,7%	100,0%
	medium/big car	100,6%	94,6%	105,7%	106,9%	95,4%	107,6%	95,9%	105,6%	101,8%	95,4%	87,0%	97,7%	103,3%	101,4%	99,6%	100,0%
	moped	105,2%	103,5%	106,3%	91,6%	100,7%	87,7%	84,2%	105,5%	89,7%	101,3%	97,8%	97,6%	100,8%	98,2%	86,0%	100,0%
	motorcycle	138,6%	133,9%	128,9%	119,7%	115,6%	110,4%	75,8%	119,5%	107,3%	79,8%	115,5%	123,6%	89,5%	115,2%	113,3%	100,0%
	light duty vehicle	95,4%	91,3%	94,1%	107,1%	101,4%	103,2%	96,7%	108,7%	100,4%	100,2%	102,8%	109,5%	100,5%	113,5%	103,0%	100,0%
	heavy duty vehicle	89,3%	100,0%	105,0%	89,4%	98,7%	96,6%	99,6%	94,8%	88,9%	104,2%	92,6%	97,2%	109,4%	97,3%	92,7%	100,0%
	bus	101,1%	98,7%	99,1%	100,1%	103,8%	100,1%	99,9%	108,7%	104,7%	99,9%	92,3%	99,1%	107,4%	97,3%	97,5%	100,0%
	coach	99,4%	96,9%	92,3%	104,2%	102,5%	105,4%	95,3%	108,8%	102,9%	105,8%	94,1%	103,0%	99,8%	102,4%	92,9%	100,0%
	passenger train	31,2%	10,0%	313,2%	119,3%	68,1%	11,1%	190,5%	657,1%	49,7%	120,7%	1,8%	31,8%	29,6%	9,2%	346,2%	100,0%
	freight train	81,2%	57,1%	436,8%	25,3%	131,6%	99,9%	258,7%	90,1%	54,2%	38,2%	12,4%	12,4%	65,9%	50,5%	242,9%	100,0%
	inland ship	114,9%	92,7%	103,4%				93,7%					98,5%				100,0%
FC/pkm	small car	38,06	33,55	39,60	36,53	31,10	35,07	33,80	28,24	27,29	33,34	31,34	35,13	27,03	36,54	37,66	34,39
	medium/big car	43,30	37,73	47,58	46,28	34,81	43,21	38,61	34,27	33,80	36,74	35,89	41,28	32,67	44,34	46,62	41,95
	moped	21,50	19,77	10,20	8,61	17,08	13,37	13,89	12,37	11,72	17,63	16,52	15,26	14,55	12,20	6,51	15,40
	motorcycle	38,04	35,45	33,22	23,53	37,99	37,14	25,24	29,06	31,76	19,92	39,10	29,81	19,78	29,14	51,84	27,04
	light duty vehicle	77,65	72,09	77,00	81,77	71,87	77,86	74,63	68,54	61,85	71,47	81,48	79,36	61,12	90,51	84,91	76,30
	bus	13,52	16,83	16,47	22,43	13,48	18,31	16,77	18,09	16,37	17,13	14,98	15,87	16,49	16,23	16,32	16,54
	coach	16,27	20,20	19,07	24,00	13,98	21,10	21,71	20,40	18,49	19,86	18,67	17,95	15,72	22,09	23,06	19,40
	passenger train	3,18	2,14	6,23	23,52	6,13	2,81	2,55	29,14	12,48	2,44	5,27	4,01	8,25	4,94	22,62	6,71
	plane	43,90	42,83	46,22	45,41	52,40	47,43	59,50	48,97	47,17	53,27	42,92	43,68	42,47	46,81	45,71	46,66
FC/pkm %	small car	110,7%	97,6%	115,1%	106,2%	90,4%	102,0%	98,3%	82,1%	79,4%	96,9%	91,1%	102,2%	78,6%	106,3%	109,5%	100,0%
	medium/big car	103,2%	89,9%	113,4%	110,3%	83,0%	103,0%	92,0%	81,7%	80,6%	87,6%	85,5%	98,4%	77,9%	105,7%	111,1%	100,0%
	moped	139,6%	128,4%	66,2%	55,9%	110,9%	86,8%	90,2%	80,3%	76,1%	114,5%	107,3%	99,1%	94,5%	79,2%	42,3%	100,0%
	motorcycle	140,7%	131,1%	122,9%	87,0%	140,5%	137,4%	93,4%	107,5%	117,5%	73,7%	144,6%	110,2%	73,2%	107,8%	191,7%	100,0%
	light duty vehicle	101,8%	94,5%	100,9%	107,2%	94,2%	102,0%	97,8%	89,8%	81,1%	93,7%	106,8%	104,0%	80,1%	118,6%	111,3%	100,0%
	bus	81,7%	101,8%	99,6%	135,6%	81,5%	110,7%	101,4%	109,4%	99,0%	103,6%	90,6%	95,9%	99,7%	98,1%	98,7%	100,0%
	coach	83,8%	104,1%	98,3%	123,7%	72,0%	108,8%	111,9%	105,1%	95,3%	102,3%	96,2%	92,5%	81,0%	113,8%	118,8%	100,0%
	passenger train	47,5%	31,9%	92,9%	350,7%	91,4%	42,0%	38,0%	434,5%	186,2%	36,4%	78,6%	59,7%	123,0%	73,6%	337,3%	100,0%
	plane	94,1%	91,8%	99,0%	97,3%	112,3%	101,6%	127,5%	104,9%	101,1%	114,2%	92,0%	93,6%	91,0%	100,3%	98,0%	100,0%
FC/tkm	light duty vehicle	506,96	484,30	558,57	650,31	540,29	623,04	551,23	654,73	681,15	656,10	531,43	930,71	488,71	705,10	695,99	595,51
	heavy duty vehicle	33,21	35,94	37,87	34,55	42,03	41,86	38,67	38,71	40,33	38,09	38,35	36,08	44,80	40,94	37,61	38,39
	freight train	1,31	2,50	1,86	8,65	2,96	4,06	1,39	8,44	17,47	0,42	3,86	1,75	8,65	0,63	10,94	1,96
	inland ship	9,76	10,54	8,17				7,74					10,32				8,98
FC/tkm %	light duty vehicle	85,1%	81,3%	93,8%	109,2%	90,7%	104,6%	92,6%	109,9%	114,4%	110,2%	89,2%	156,3%	82,1%	118,4%	116,9%	100,0%
	heavy duty vehicle	86,5%	93,6%	98,6%	90,0%	109,5%	109,0%	100,7%	100,8%	105,1%	99,2%	99,9%	94,0%	116,7%	106,6%	98,0%	100,0%
	freight train	66,5%	127,2%	94,5%	440,7%	150,7%	206,6%	71,0%	430,0%	889,5%	21,3%	196,5%	89,1%	440,3%	32,3%	557,2%	100,0%
	inland ship	108,7%	117,3%	91,0%				86,2%					114,9%				100,0%

In graph:

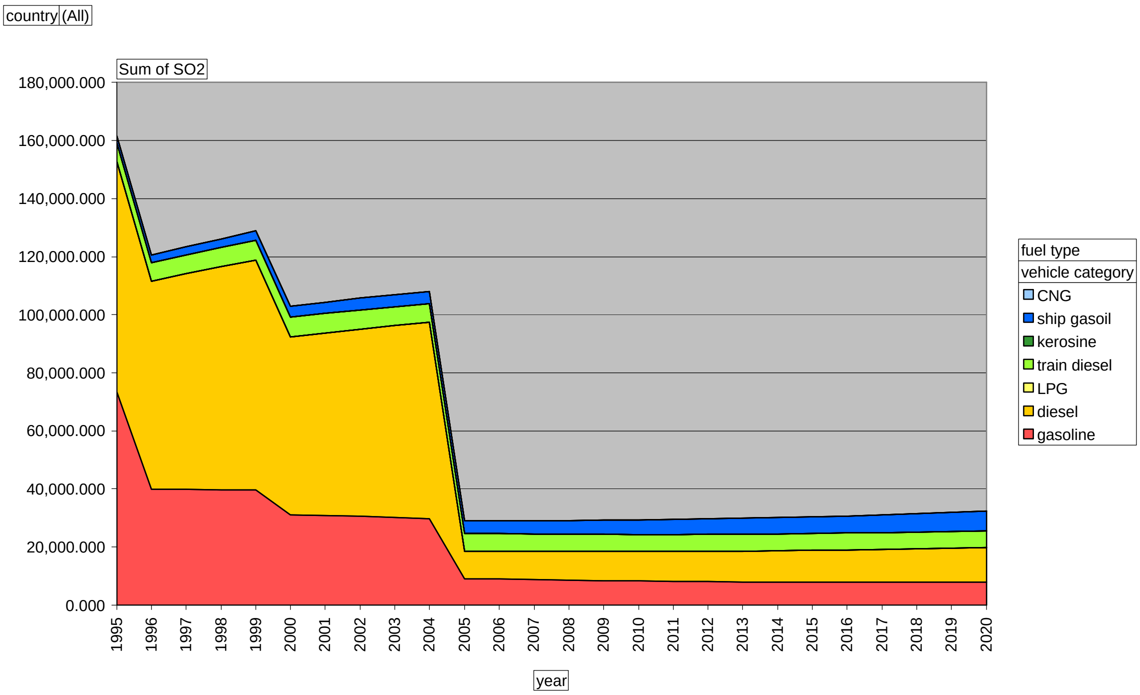
Figure 29: Fuel consumption per pkm – small cars, 2000



5.7.3 Sulphur emissions

The figure below gives the total SO_2 emissions in EU15 per fuel type. Note the stepwise decrease due to the new road fuel standards.

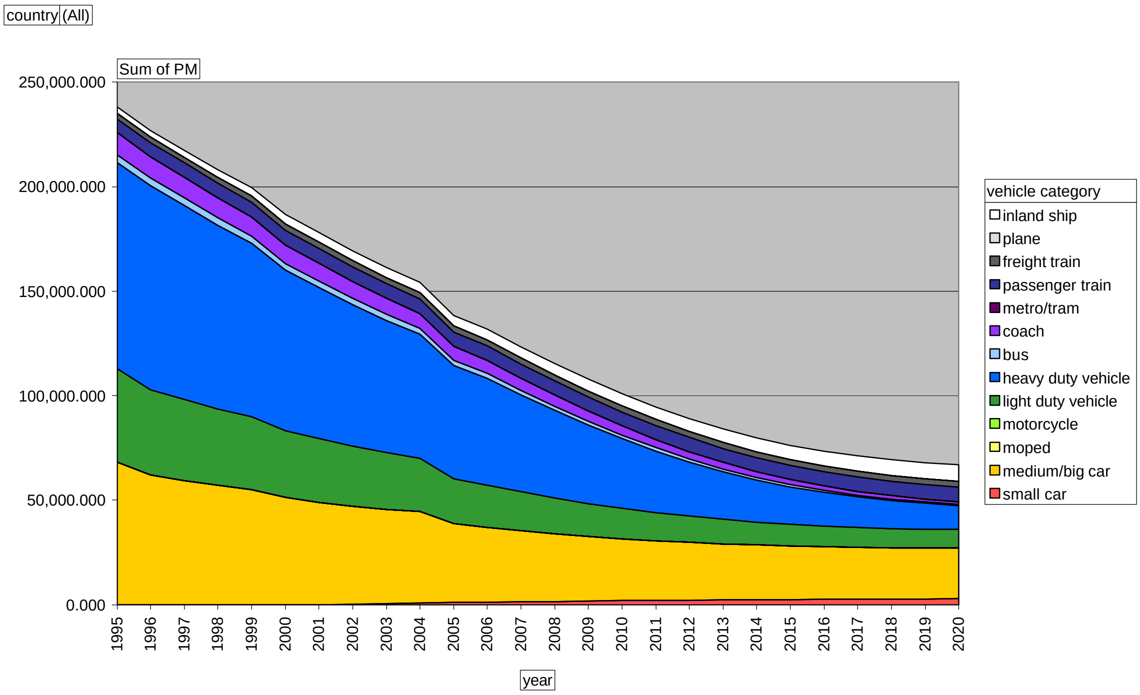
Figure 30: SO_2 emissions in EU15 for all modes (except electric), per fuel type



5.7.4 PM emissions

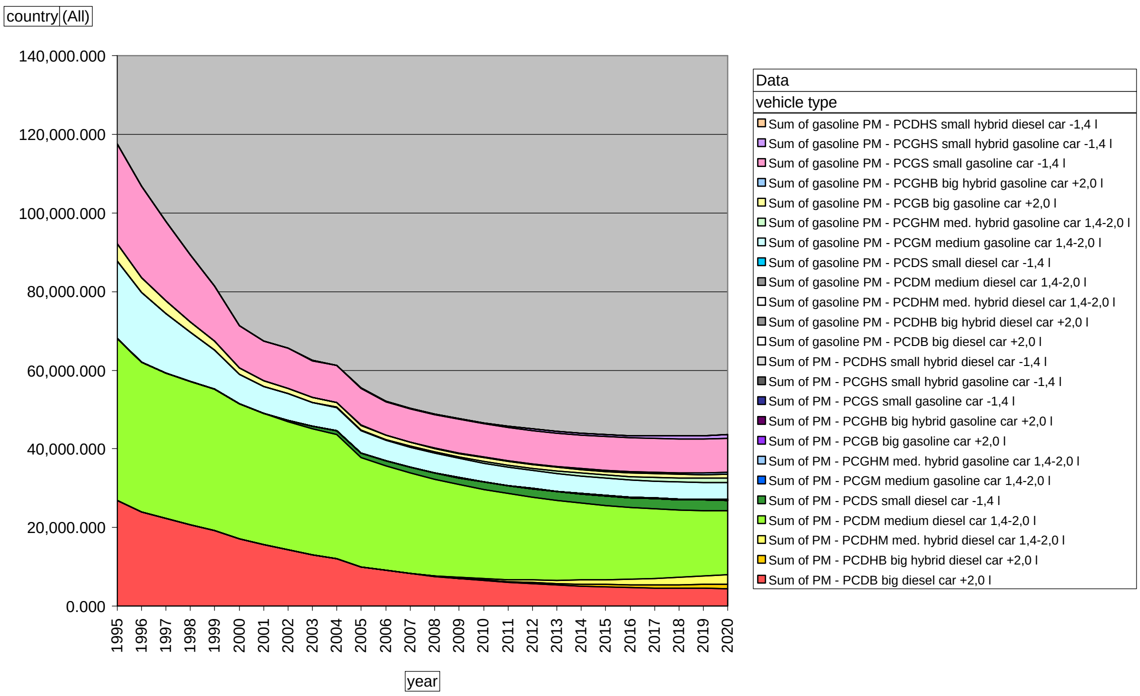
The figure below gives an overview of the diesel PM emissions for road transport in EU15.

Figure 31: PM emissions in EU15 for all modes (except electric) – diesel



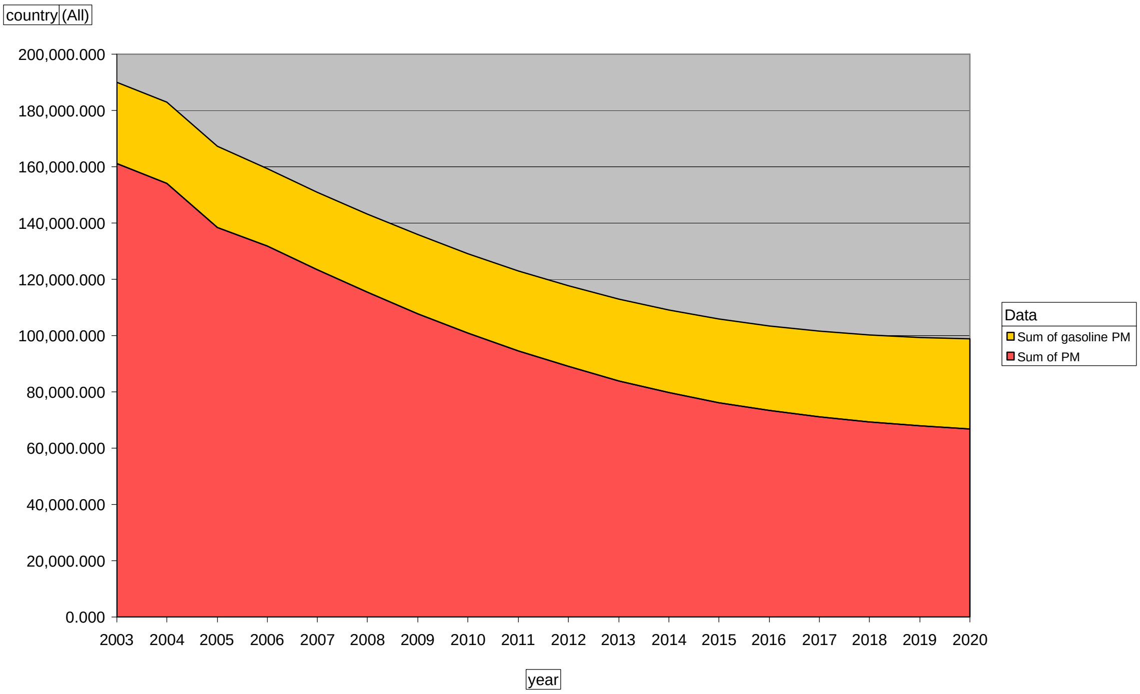
The figure below gives the PM emissions for passenger cars in EU15.

Figure 32: PM emissions in EU15 for passenger cars – diesel and gasoline



An in depth view on the gasoline / diesel share in PM emissions can be found in the next figure.

Figure 33: Share of gasoline PM in total PM emissions for passenger cars in EU15

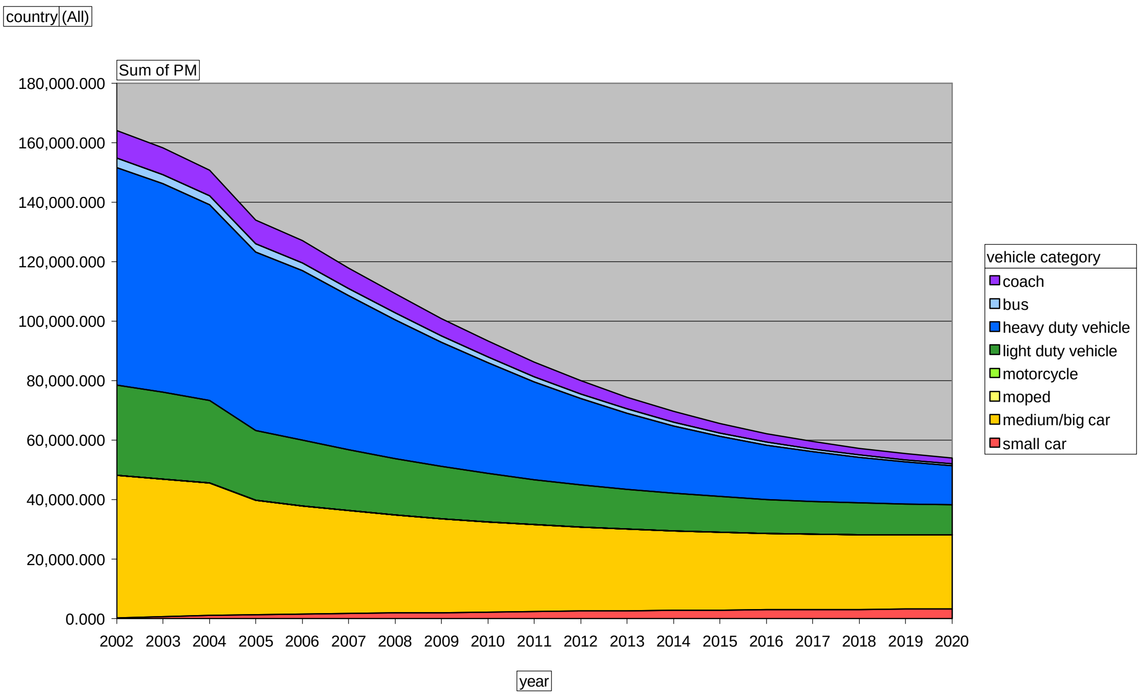


"Sum of PM" is diesel PM

The next figure gives the same results for EU15 + NO, CH + CZ, HU, PL, SI.

The road vehicle stock model for the new Member States does not start from 1995, but from 2000 (SI), 2002 (HU and PL) and 2003 (CZ). Therefore, a little bump can be notified in the total emissions.

Figure 34: PM emissions in all 21 modelled countries for road vehicles – diesel



The figures below show the same results for 3 separate countries: France, Germany and Poland.

Figure 35: PM emissions in France for all modes (except electric) – diesel

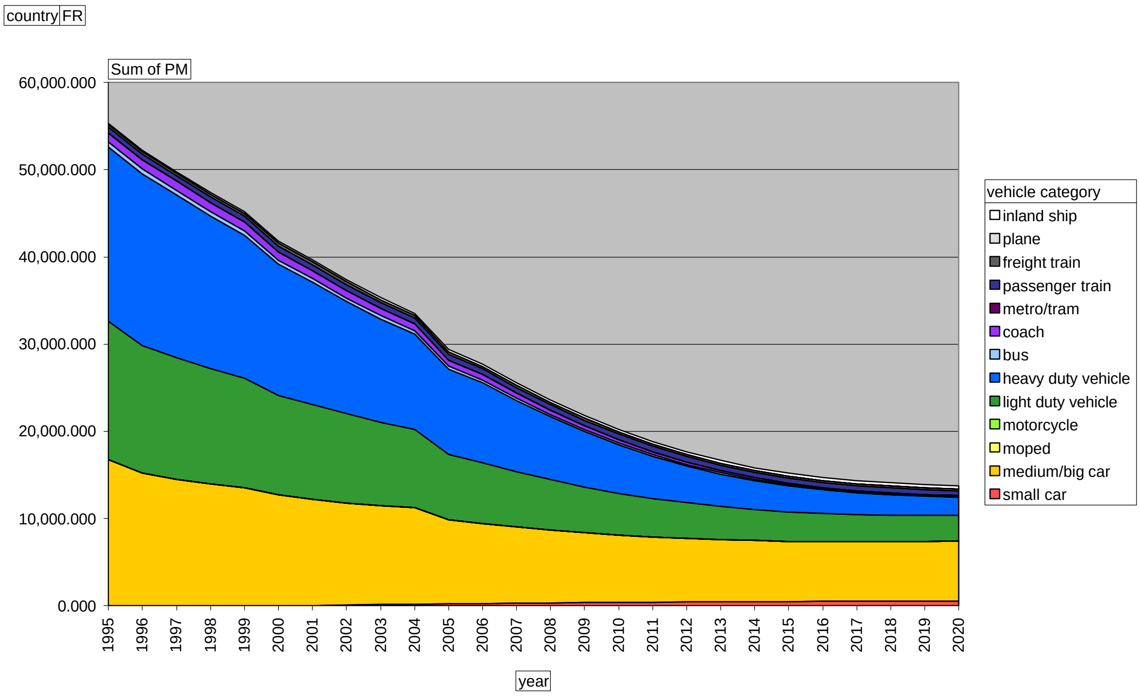


Figure 36: PM emissions in France for passenger cars – diesel and gasoline

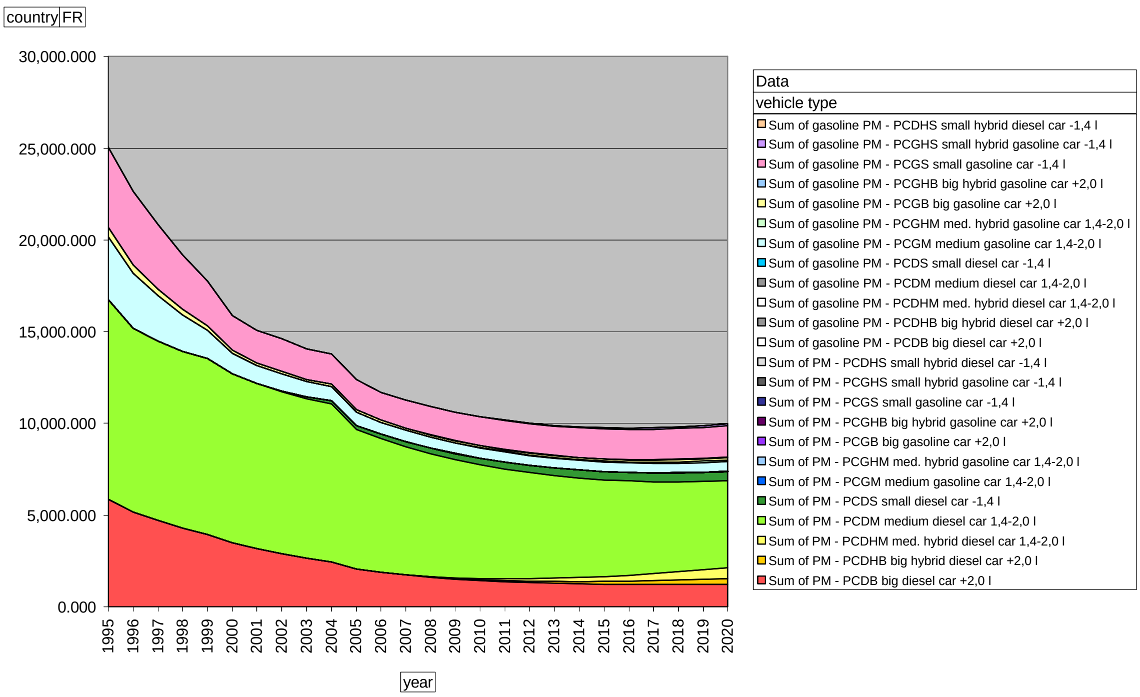


Figure 37: PM emissions in Germany for all modes (except electric)) – diesel

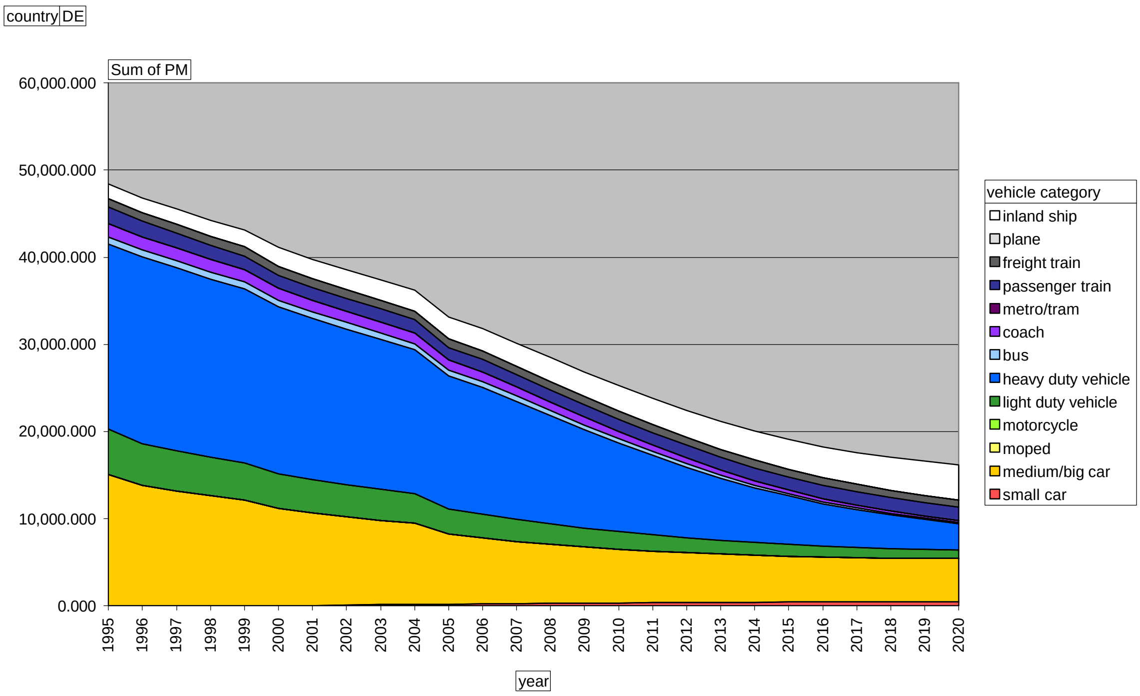


Figure 38: PM emissions in Germany for passenger cars– diesel and gasoline

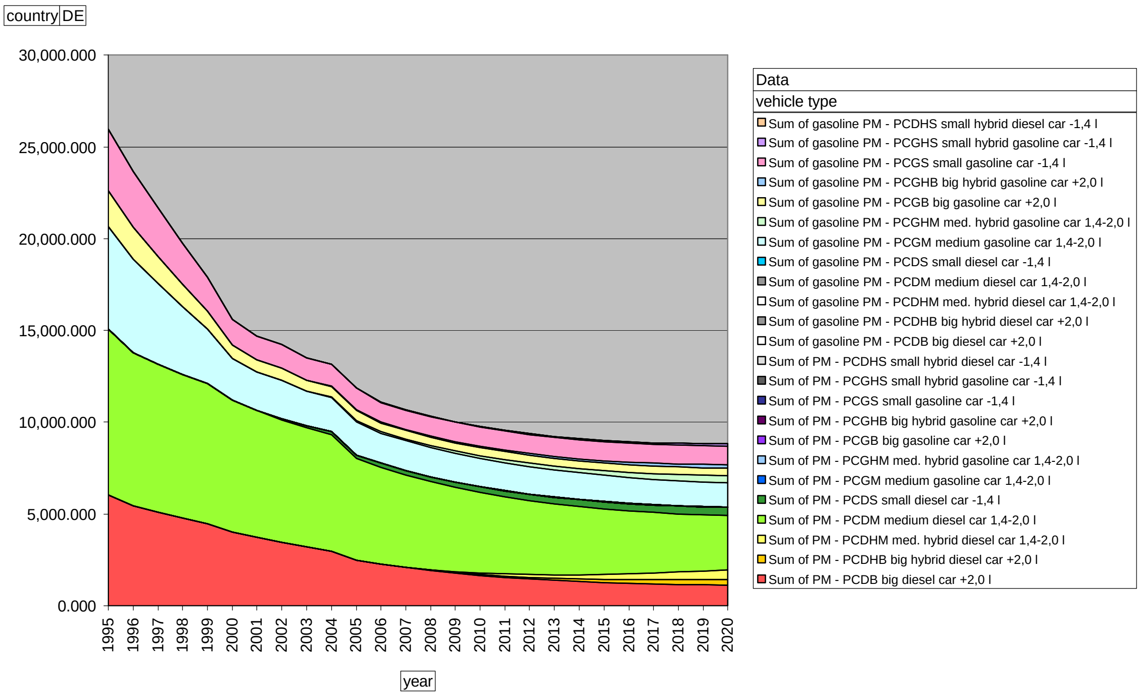
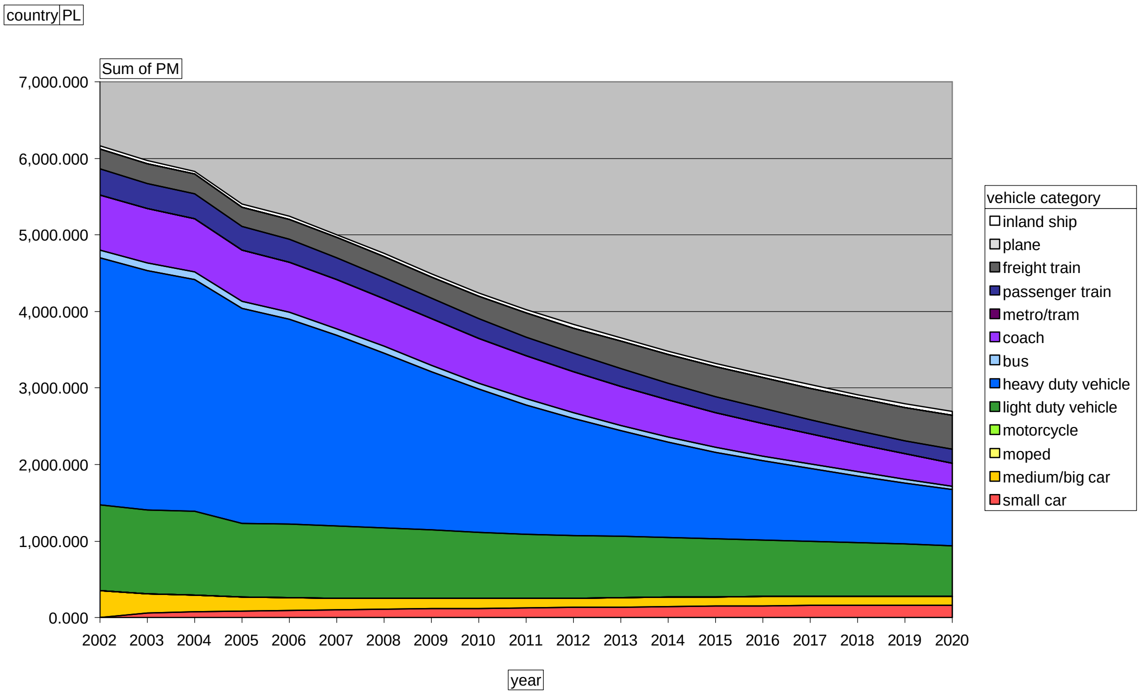
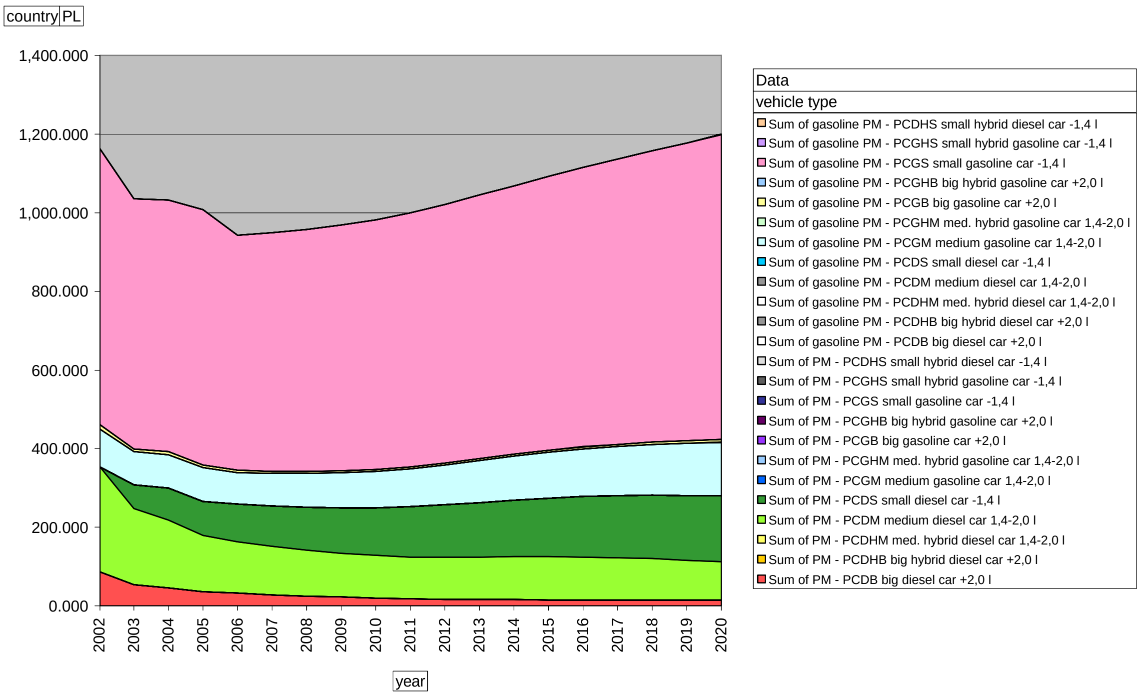


Figure 39: PM emissions in Poland for all modes (except electric)) – diesel



Note: the PL model only starts in 2002.

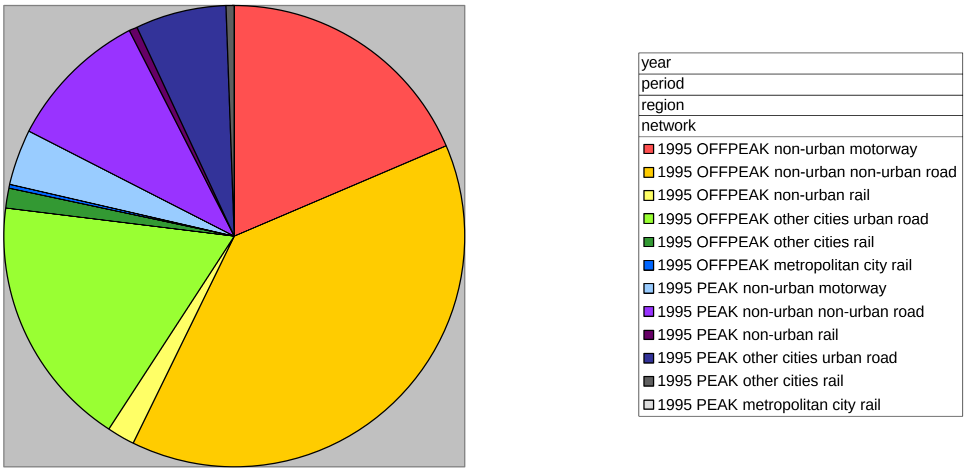
Figure 40: PM emissions in Poland for passenger cars– diesel and gasoline

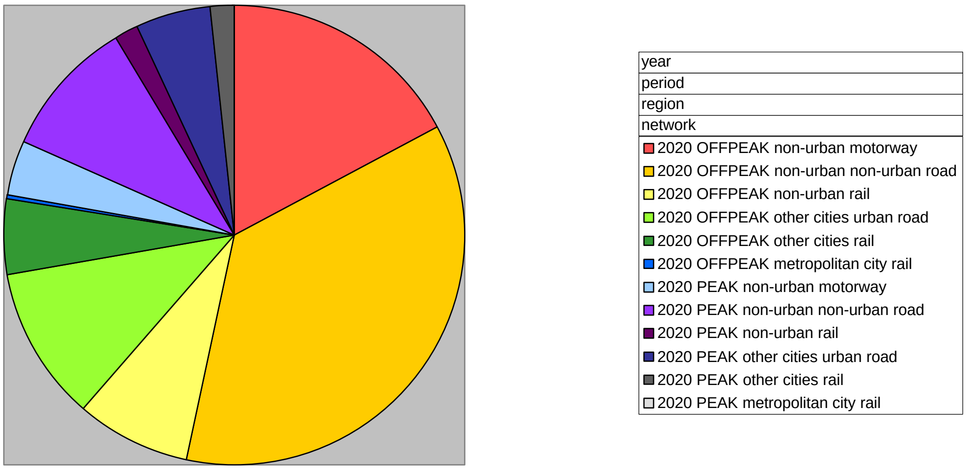


5.7.5 NO_x emissions

The figures below compare the NO_x emissions in the UK between 1995 and 2020.

Figure 41: Total NO_x emissions (except air) in UK by region, network and period in 1995 and 2020





6 The Lifecycle emission module

6.1 Objective and scope of the lifecycle emission module

In general, the scope of environmental lifecycle assessment studies varies from rather narrow approaches focusing on emissions during the life of a product up to very broad approaches taking into account all emissions related to the production process, life and disposal of a product as well as the impacts of the use and depletion of raw materials. In TREMOVE a restricted lifecycle assessment module is implemented, focusing on the fuel cycle only.

To concentrate on fuel implies that not only the "operational" emissions of vehicles, but also the emissions to the air due to production and distribution of fuel (and electricity) are taken into account. Since the operational emissions tend to decrease in the future, the relative share of the "pre-processor" emissions will increase and might become substantial. In addition, to include the production step of the fuel respectively electricity allows to assess policies aiming at changes of the modal split. This is particularly important for rail which uses electricity as propulsion system.

6.2 Structure of the lifecycle emission module

For each year and each country the lifecycle module derives the total fuel (and electricity) consumption by aggregating the outcomes of the fuel consumption and emissions module. Next to total electricity consumption (in kWh), total fuel consumption (in tonnes) is calculated for the following fuels[108] :

- Road vehicle diesel
- Road vehicle gasoline
- Road vehicle liquefied petroleum gas (LPG)
- Road vehicle compressed natural gas (CNG)
- Rail vehicle diesel
- Inland waterway vessel gasoil (in the base case assumed to be marine gasoil 0,2% sulphur)
- Aircraft kerosine

The "lifecycle" emissions to the air due to the production of the fuels (and electricity) then are calculated by multiplying total consumption with an appropriate emission factor for the fuel. Such emission factors are included for the following pollutants : CO, NO_x, PM, NM-VOC, CH_4, SO_2 and CO_2. Sources and levels of the emission factors are discussed in the following section of this report.

Assuming that most power plants and fossil fuel refinery facilities are located outside urban areas, the lifecycle emissions are allocated to the non-urban regions in TREMOVE.

[108] Maritime fuels are not yet included in the life cycle module. A separate module for maritime fuels will be completed once full information on the fuel types to be used in maritime policy simulations is available.

6.3 Sources and levels of the life cycle emission factors

6.3.1 Emission factors for fuel production and distribution

Lifecycle emission factors for fossil fuels were derived by INFRAS from the Swiss ECOINVENT database[109]. The emission factors represent emissions related to fuel production as well as fuel distribution up to regional filling stations and emissions at the filling stations themselves (except for LPG). Also additional emissions related to the need for the production of low-sulphur fuels for road transport have been taken into account. No differentiation of emission factors over countries has been introduced in TREMOVE.

The authors regret that the Code Of Practice of ECOINVENT does not allow to publish the levels of the emission factors included in TREMOVE in this report.

6.3.2 Emission factors for electricity production

A specific issue with respect to the electricity production emission factors is their spatial distribution and evolution over time. Since the mix of the electricity production plants varies from country to country (and over time), the emission factors associated with electricity production vary substantially. In this context it was decided to assure a maximum level of consistency with the RAINS and PRIMES models. As far as possible, electricity production factors thus were derived from the latter models.

For NO_x, NMVOC, PM and SO_2 electricity production emission factors by country have been provided to the TREMOVE team by the RAINS model team for the years 2000, 2010 and 2020. As, in contrast with RAINS, TREMOVE operates at a year-per-year timescale, 2000 values have been used for the 1995-2000 period and linear interpolation was performed for the 2001-2020 period. With respect to CO_2 emission factors were provided by the PRIMES model team. CH_4 and CO emission factors have been taken from MEET[110].

[109] Ecoinvent Centre (2004), ecoinvent data v1.1. Swiss Centre for Life Cycle Inventories, Dübendorf, 2004
[110] Meet, 1999. With the available information it was not possible to construct a time series consistent with PRIMES and RAINS – constant 1995-2020 factors are applied.

The table below displays the factors used for France and Germany.

Table 56: Electricity emission factors in the lifecycle module

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
France														
CO	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012
NO_x	0,255	0,255	0,255	0,255	0,255	0,255	0,238	0,222	0,205	0,188	0,171	0,155	0,138	0,121
PM	0,023	0,023	0,023	0,023	0,023	0,023	0,022	0,021	0,019	0,018	0,016	0,015	0,014	0,012
NMVOC	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,009	0,009	0,009	0,008	0,008	0,008
CH_4	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130
SO_2	0,360	0,360	0,360	0,360	0,360	0,360	0,332	0,304	0,275	0,247	0,219	0,191	0,162	0,134
CO_2	65,941	69,174	72,406	75,639	78,871	82,104	81,125	80,147	79,169	78,190	77,212	78,748	80,283	81,819
Germany														
CO	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098
NO_x	0,452	0,452	0,452	0,452	0,452	0,452	0,434	0,415	0,397	0,378	0,360	0,341	0,323	0,304
PM	0,035	0,035	0,035	0,035	0,035	0,035	0,033	0,032	0,030	0,028	0,026	0,025	0,023	0,021
NMVOC	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,012
CH_4	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674
SO_2	0,495	0,495	0,495	0,495	0,495	0,495	0,473	0,451	0,429	0,407	0,384	0,362	0,340	0,318
CO_2	619,64	605,10	590,55	576,00	561,46	546,91	543,77	540,63	537,49	534,35	531,21	526,93	522,66	518,38

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2009	2010
France														
CO	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012
NO_x	0,104	0,087	0,086	0,085	0,084	0,083	0,082	0,081	0,080	0,079	0,078	0,077	0,104	0,087
PM	0,011	0,009	0,010	0,011	0,011	0,012	0,012	0,013	0,014	0,014	0,015	0,015	0,011	0,009
NMVOC	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007
CH_4	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130
SO_2	0,106	0,078	0,074	0,070	0,066	0,062	0,058	0,055	0,051	0,047	0,043	0,039	0,106	0,078
CO_2	83,355	84,891	84,969	85,047	85,125	85,203	85,281	90,356	95,431	100,51	105,59	110,66	83,355	84,891
Germany														
CO	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098	0,098
NO_x	0,286	0,267	0,263	0,258	0,253	0,248	0,244	0,239	0,234	0,229	0,225	0,220	0,286	0,267
PM	0,019	0,018	0,017	0,016	0,015	0,014	0,014	0,013	0,012	0,011	0,010	0,009	0,019	0,018
NMVOC	0,012	0,012	0,013	0,013	0,014	0,015	0,015	0,016	0,016	0,017	0,018	0,018	0,012	0,012
CH_4	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674
SO_2	0,296	0,274	0,265	0,255	0,246	0,237	0,228	0,219	0,209	0,200	0,191	0,182	0,296	0,274
CO_2	514,10	509,83	504,45	499,07	493,68	488,30	482,92	492,97	503,01	513,06	523,10	533,15	514,10	509,83

7 The maritime model

7.1 The model structure

TREMOVE describes transport in a geographical area to describe the transport related emissions adequately. Therefore maritime transport is treated separately and not coupled directly to the different country models. The European sea area is therefore subdivided in 8 modelled maritime areas. These sea regions are the North Sea, the Irish Sea, the English Channel, the Baltic Sea, the Black sea, the NE Atlantic, the Mediterranean and the remainder of the EMEP area.

Within these 8 sea regions TREMOVE will cover freight vessels and ferries. Fishing vessels are not included.

Different reasons suggest that the modelling approach adopted for the other modes (using CES trees) is not feasible for maritime transport. Some of the major reasons are that maritime transport is weakly represented in the SCENES model and that the substitution possibility between maritime transport and other modes is very limited. Moreover, for an important share of maritime movements, starting ports and/or destination ports are not located in Europe.

Another problem is that there is no data available from ENTEC on the split in short sea and deep sea shipping. Only short sea shipping is expected to compete with land transport modes.

The approach adopted for maritime transport in TREMOVE is based on the recent work performed by ENTEC on activity and emissions from ships in the European Community[111].

Maritime transport demand is considered exogenous. As substitution possibilities between maritime transport and other modes are very limited, it is assumed that the maritime movements will not be affected by policy measures. This implies that coverage of policy options for maritime transport are restricted to policies affecting ship technology and ship fuels.

7.2 Maritime baseline data

The primary source of information in terms of freight ship movements in this study was the database provided by Lloyds Marine Intelligence Unit. This is the only commercial database on all ship movements worldwide and links data on movements to port callings, vessel types, engine types and vessel sizes. The database covers all ships greater than 500 tons; smaller freight vessels were not taken into account in the study. In the ENTEC study, Lloyds data on four months in 2000 was analysed and extrapolated to twelve months to estimate freight ship movements and port callings per vessel type in the year 2000.

In their study, ENTEC reported maritime movements by engine type and fuel used. Moreover they noted that irrespective of ship category (container, passenger ferry,…) the installed engine type on board of a ship and the fuel used largely dictates the ship's emissions. Therefore, ENTEC derived emission factors for five different engine types and three different fuel types from published sources.

[111] Quantification of emissions from ships associated with ship movements between ports in the European Community (ENTEC, July 2002).

This was repeated for three activities or operating modes of the ships: at sea, in port and manoeuvring. Combining movement data and emission factors, total on-sea and in-port emissions were derived for the sea regions and ports considered. The full emission calculation methodology developed by ENTEC has been included in the TREMOVE model. The reader therefore is referred to the ENTEC report for further details.

Although ENTEC used these 2000 movement figures and fuel consumption figures to develop a forecast until 2020, the ENTEC forecasts were not adopted in TREMOVE. On the contrary, in order to develop a maritime transport baseline up to 2020, growth rates derived from SCENES were applied to the 2000 ENTEC figures. This approach guarantees the consistency of the TREMOVE baseline across modes.

As substitution possibilities between maritime transport and other modes are very limited, it is assumed that the baseline maritime movements will not be affected by policy measures. This implies that coverage of policy options for maritime transport are restricted to policies affecting ship technology and ship fuels.

Maritime vkm and emissions are calculated:

- Per country (port callings) for 1995-2020
- Per sea (8 seas) for 1995-2020

The maritime ship vkm are detailed into 27 ship types, 6 engine types and 3 fuel types.

7.2.1 Port callings per country

The number of port visits in 1995 is derived form the ENTEC data. A growth factor from the SCENES model has been applied to calculate the figures for 1996-2020.

The amount of visits for each year has been multiplied with an emission factor per port visit in order to achieve the total emissions.

7.2.2 Sea freight maritime transport

The number of ton-kilometre per sea in 1995 is derived form the ENTEC data. A growth factor from the SCENES model has been applied to calculate the figures for 1996-2020.

The amount of vkm for each year has been multiplied with an emission factor per vkm in order to achieve the total emissions. The emission factor consists of the emission of the mean engine (ME) + the emission of the auxiliary engine (AE).

The source of the emission factors is the ENTEC report.

7.2.3 Sea ferry transport

For ferry vessel movements in 2000, ENTEC adopted a different approach. Ferry movements were estimated by identifying the maximum number of crossings possible in one day and applying seasonal ratios to derive the real number of crossings per day. The ratios were derived from published timetable information for selected ferries.

7.3 Modelling of policy simulations

Including options for simulations has not yet been implemented, but is foreseen for the next model update (version 2.3), once there is clear definition of policies to be simulated.

Given that these policies seem to focus on after-treatment technology and shore-side electricity, rather than changes in the engines themselves, modelling shifts between ship types might be a bridge too far for the purpose of CAFE.

8 The Welfare module

To evaluate policies in TREMOVE, a welfare assessment is made. Differences in welfare between the base case and the simulated policies are calculated. Below we review first some basic concepts with respect to welfare economics. Next, we explain how these have been translated into TREMOVE.

8.1 Welfare economics, basic concepts

Social welfare can be considered as the sum of 4 components:

- the consumer surplus,
- the producer surplus,
- taxes-subsidies
- external effects.

These four components have to be expressed in monetary terms, which enables on to compute a global level of social welfare.

8.1.1 Basic case

The figure below shows a demand curve and a supply curve for a good X. In equilibrium a quantity x is bought for a price p.

The demand curve expresses what people are willing to pay for a good. Each point on the demand curve expresses the marginal utility for consumers of an extra unit of the good and as a consequence the marginal benefit for society.

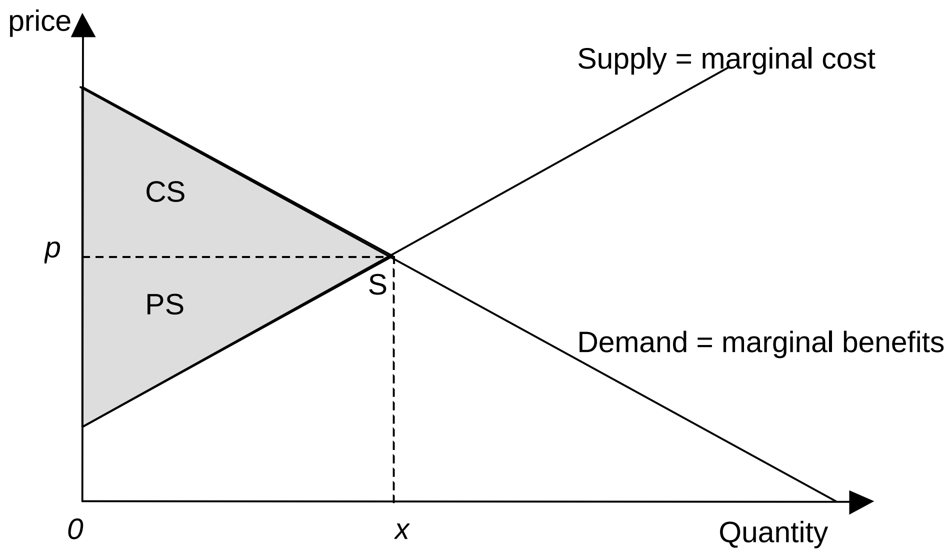
The supply curve expresses the cost of a producing the good. Each point on the curve expresses the marginal cost of an extra unit of the good produced for producers and as a consequence also the marginal cost for society.

The difference between marginal benefits for society and marginal costs for society is the gain in social welfare. This is can be graphically seen on the figure below. The total utility or willingness to pay given the equilibrium is given by the area under the demand curve limited by 0xSA. The total cost to society is given by the area under the supply curve. This is the area limited by 0xSB. The shaded area BSA indicates the gain in social welfare. The gain in social welfare can be attributed to consumers, the consumersurplus and the producer surplus. This is explained below.

The price is determined as the crossing between supply and demand curve. A majority of consumers is nevertheless willing to pay more than the actual price on the market as can be seen on the demand curve. Thanks to this phenomenon, consumers (and society) get a utility, they have not to pay for, the producer surplus (PS). The story is similar for the producers. A majority of suppliers supply goods at a cost lower than the price. This procures suppliers (and society) an extra profit, the producer surplus (PS).

The sum of producer and consumer surplus is the social welfare for this simple case.

Figure 42: Social welfare: consumer surplus and producer surplus

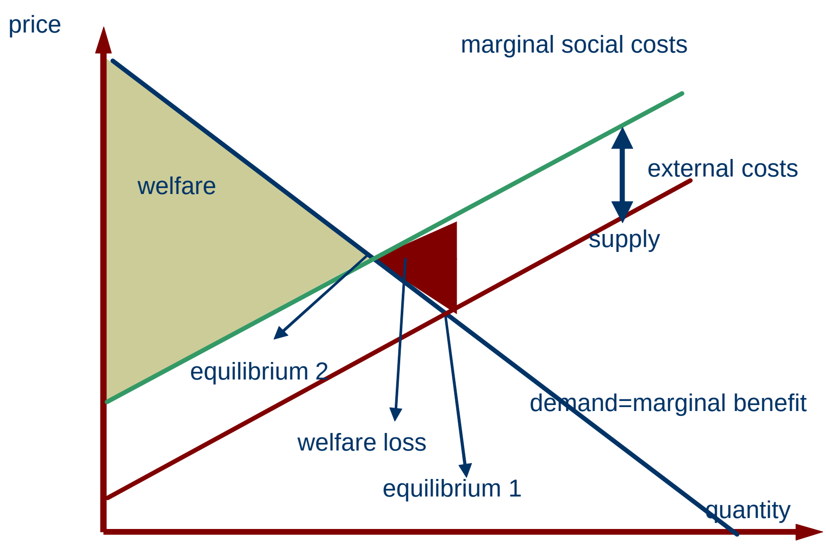


8.1.2 External effects, taxes and subsidies

Most often reality is more complicated than described above. Prices do not take always all costs into account linked to the consumption/production of the good. A car user taking its car causes emissions, negative health effects as a consequence and thus an extra cost to society.. Such an effect is a negative externality. An externality can also be positive. Social welfare has to be corrected for this external effects.

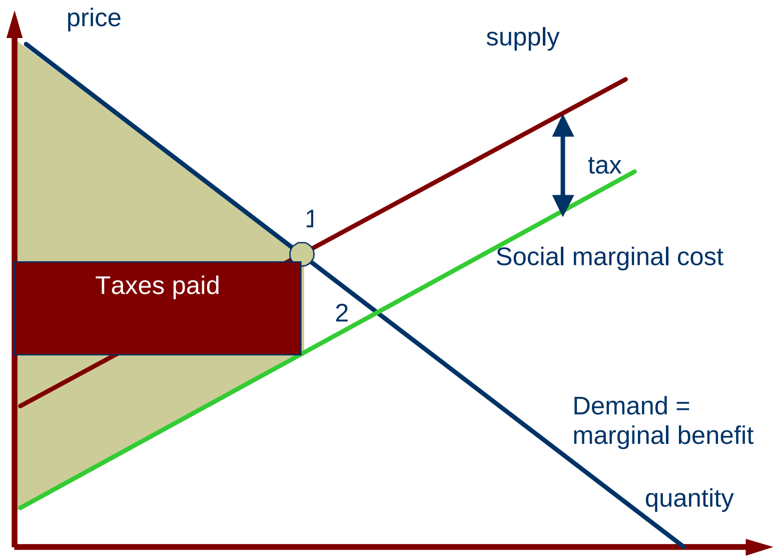
The figure below shows a situation with an external effect. Market equilibrium 1 does not take the external effect into account, but only the private costs. This is not an optimal situation from a social welfare point of view. Social marginal costs are higher than the social marginal benefits (= demand). Each unit consumed beyond equilibrium 2 reduces social welfare. The welfare loss is indicated on the figure.

Figure 43: Effect of external cost on welfare



Also a tax or a subsidy will have a distortion effect [112]and welfare will have to be corrected for this effect. The figure below shows a market with a tax. Due to the taxes, consumers and producers do not get the same consumer and producer surplus as in the case without taxes apparently. However the taxes levied by the government will return in one way or another to consumers and/or producers under the form of a transfer, a subsidy, a reduction in another tax, …. This means that taxes have to be added to the calculation of social welfare. For subsidies, the opposite is true.

Figure 44: Transport market with a tax



As a conclusion, we can state that social welfare can be computed as the sum of consumer surpluses, producer surpluses, taxes less subsidies and external effects of all markets. Negative external effects are written with a negative sign, positive external effects with a positive sign.

W = CS + PS + ? (Taxes - Subisidies)[113] - Negative externalities + Positive externalities

Remark that TREMOVE looks only at global welfare and not on the distribution of welfare. In other words, TREMOVE do not attach a different weight to a euro of poor people in comparison a euro of rich people.

8.2 Application in TREMOVE

Hereunder we explain how the above principles have been applied in TREMOVE.

First we have to keep in mind that TREMOVE is a partial equilibrium model. The transport market is modelled in detail and changes in one transport market will have influences in other transport markets. Even a shift between transport and non transport goods is possible. Global income and production level however will remain constant.

[112] If the taxes or subsidies do not correct for an external effect

[113] ? is a correction factor taking into account efficiency of tax regimes. Some explanation are given for the TREMOVE case further on.

8.2.1 Difference in consumer surplus between base case and simulation case (CS_{diff})..

TREMOVE calculates the difference between marginal benefits for society, (this is the utility or the willingness to pay for consumers) given by the demand curve and the marginal costs for society, the supply curve. TREMOVE does not calculate separately consumer surplus and producer surplus.

Total utility is calculated in the demand module thanks to the nested CES function, described in the chapter on the demand module. The highest node of the CES tree for private transport provides a utility measure Q and a price per unit of utility P for a given income in the base case and the simulation case. To compute the difference in utility we take the base case utility unit price and multiply it with the difference in utilities between base case and simulation case.

$CS_{diff} = (Q_{simulation} - Q_{base\ case}) * P_{base\ case}$

This value is calculated for each year in the demand module and imported into the welfare module.

Total production costs X are calculated in the business transport tree thanks to the nested CES function. The highest node of the CES tree for business transport provides total production costs for a fixed production level.

$PS_{diff} = X_{simulation} – X_{base\ case}$

This value is calculated for each year in the demand module and imported in the welfare module.

8.2.2 Differences in taxes between base case and simulation case (PS_{diff}).

Taxes and VAT are calculated at the lowest nodes in the CES tree in the demand module. A value for base case and simulation case is for each year transferred to the welfare module. This value is adapted for the value of marginal cost of public funds. The value of marginal cost of public funds, ?, expresses that different forms of taxes have different efficiencies.

? = 1 when the tax revenue is returned to the households in a lump sum way and when there are no distortions in the economy
? = 0 when the money is wasted by the government

A labour tax for example has a negative effect on the labour market, as it reduces the labour supply and as a consequence social welfare. For Belgium, a country with high labour taxes, each euro that has to be raised by labour taxes has an efficiency cost of 2.52 Euros. At the opposite site, a tax compensating for an external effect will reduce market distortions and will increase social welfare.

Generally speaking, if transport taxes enable authorities to avoid more taxes on labour or to reduce these taxes, transport taxes have to be increased by a factor ? for the welfare calculation. Actually a ? of 1,0660 is applied to correct tax amounts levied in the transport sector.

8.2.3 Differences in external costs between base case and simulation

8.2.3.1 External congestion costs:

TREMOVE works with generalized prices (resource cost + time cost) in the demand module. The private time cost for each vehicle kilometre is incorporated. The total time cost for all vehicle kilometres has thus already been taken into account in the calculation of the production costs. No further correction for congestion needs to be made for the welfare calculation.

8.2.3.2 Environmental costs

To be able to calculate a welfare measure, emissions have to be expressed in monetary terms. All emissions reported in the emission module will be monetized. Values for external costs per ton pollutant have been exclusively taken from the CBA in the CAFE program except for CO values. The external costs of CO have been taken from ExternE (Friedrich, Bickel 2001)[114].
Unfortunately, CBA team could not finalize their report yet. For this reason, external cost data are not available yet at a detailed level. Normally, more detailed figures should come available in January.

Climate change values

For climate change we use the external cost data as described in the CBA. CBA suggests climate change values as these have their importance in trade off analyses between measures with both health effects and climate change effects.

CO_2 values proposed are growing from 2010 to 2020 from 12 to 20 €/ton, N_2O and CH_4 values are calculated by applying the IPCC 2001 global warming potential to the CO_2 values respectively 296 and 23. For 2005 till 2010 costs were retropollated taking into account a same annual cost growth as for the 2010-2020 period. For 1995 to 2005 we will use 2005 data of 8 €. Data prior to 2005 are in fact of no importance as base case and simulation will not differ. (Policies can have no effect in the past.)

Air pollution values for VOC, PM, NO_x, SO_2, CO

The CBA external cost value for VOC is used for both CH_4 and NMVOC. As a consequence, the external cost of CH_4 is the sum of its climate change and air pollution component.

The C_6H_6 (benzene) emissions from road are not treated separately as they are already included in the NMVOC. In the input file external costs for C_6H_6 are therefore put equal to zero. Also values VOC values are put equal to zero as the calculations are made for CH_4 and NMVOC.

For TREMOVE PM10, we use the CBA external cost values for PM2.5. This is reasonable as 90 to 95% of transport PM is PM2.5[115]. The PM external costs are differentiated between non-urban, urban and metropolitan areas.

Also for SO_2 and NO_x, we use CBA values.

External costs for air pollution are expressed in $€_{2003}$/ton. These values for air pollution have been recalculated into $€_{2000}$ via the European Harmonised Index of Consumer Prices published by the European Central Bank.

[114] Rainer Friedrich, Peter Bickel, Environmental External costs of Transport, 2001
[115] Paul Watkiss, projectleader of CBA study suggested us to use CBA values in this way

Except for PM no geographically differentiated values are available. Different external cost values are given for rural, other urban areas and metropolitan areas. No further geographical distinction (between countries) is made. TREMOVE is ready to treat future external cost values differentiated per country, per region and over time for road, rail, inland waterway and life cycle emissions[116]. Also for air[117] and maritime emissions TREMOVE is able to allocate different costs to these.

The table presents the external cost values in €$_{2000}$/ton /ton used for Germany.

Table 57: External costs for Germany in €$_{2000}$/ton

pollutant	region	2000	2005	2010	2015	2020
CO	non-urban	0,2	0,2	0,2	0,2	0,2
CO	other cities	1,73	1,73	1,73	1,73	1,73
CO	metropolitan	1,73	1,73	1,73	1,73	1,73
NO_x	non-urban	4027	4027	4027	4027	4027
NO_x	other cities	4027	4027	4027	4027	4027
NO_x	metropolitan	4027	4027	4027	4027	4027
PM	non-urban	41946	41946	41946	41946	41946
PM	other cities	137891	137891	137891	137891	137891
PM	metropolitan	408547	408547	408547	408547	408547
NMVOC	non-urban	1686	1686	1686	1686	1686
NMVOC	other cities	1686	1686	1686	1686	1686
NMVOC	metropolitan	1686	1686	1686	1686	1686
CH4	non-urban	1870	1870	1962	2054	2146
CH4	other cities	1870	1870	1962	2054	2146
CH4	metropolitan	1870	1870	1962	2054	2146
SO_2	non-urban	4307	4307	4307	4307	4307
SO_2	other cities	4307	4307	4307	4307	4307
SO_2	metropolitan	4307	4307	4307	4307	4307
N_2O	non-urban	2368	2368	3552	4736	5920
N_2O	other cities	2368	2368	3552	4736	5920
N_2O	metropolitan	2368	2368	3552	4736	5920
CO_2	non-urban	8	8	12	16	20
CO_2	other cities	8	8	12	16	20
CO_2	metropolitan	8	8	12	16	20

External cost values for CO have been taken from ExternE. Values are geographically different. Unfortunately, ExternE does not cover all European areas. For this reason we used external cost values from one area for another area. Increasing uncertainty and errors are inherent to this method.

The table below indicates the data that was used for countries with no data are available in ExternE.

Table 58: Origin of data for countries having no estimate in ExternE

costs from …	are also used for …
Belgium	Luxemburg
Finland	Sweden, Norway and Denmark
France	Spain, Portugal and Italy
Germany	Poland, Czech Republic, Austria, Hungary,

[116] The actual unavailability of differentiated external costs increases the uncertainty and error margins of the welfare cost estimates. Actually, TREMOVE treats inland waterway emissions and life cycle emissions like non urban road emissions.
[117] For air a distinction between LTO (landing and take off) and cruise is foreseen, for maritime between sea and port emissions.

	Switzerland
UK	Ireland

The Netherlands and Greece have their own estimation.

ExternE gives most often an estimate for a rural area and one for an urban area. The urban estimate is used for TREMOVE metropolitan and urban area.

8.2.3.3 Other external costs

No other external costs other than those mentioned above have been taken into account.

8.2.4 Actualisation - net present value

After having calculated differences between welfare values for the base case and the simulation for all years, these differences are actualized with 2005 as base year using an actualization discount rate of 4%. Then the actualized differences are summed and indicate us whether welfare increased or decreased in the simulation. A positive sign for the sum means an increase in welfare, a negative sign a decrease.

9 Comparison with other baselines

9.1 Comparison with Transport In Figures

The TREMOVE results have been compared to Transport In Figures[118]. The SCENES model has been calibrated to fit the TIF figures, and as SCENES fits directly into the TREMOVE transport demand module, TREMOVE is also fully consistent with TIF.

In the table below, the number of passenger-km and ton-km in the TREMOVE baseline and reported by Transport in Figures can be found.

Table 59: Comparison TREMOVE – Transport in Figures for EU15 (million pkm or tkm per year)

TIF vehicle category		1995	2000
passenger cars (table 3.5.4)	pkm TREMOVE	3.505.700	3.727.778
	pkm TIF	3.480.600	3.734.900
	TREMOVE / TIF pkm	0,72%	-0,19%
powered two wheelers (table 3.5.5)	pkm TREMOVE	128.960	149.492
	pkm TIF	128.960	150.160
	TREMOVE / TIF pkm	0,00%	-0,44%
road haulage (table 3.4.5)	tkm TREMOVE	1.164.522	1.399.719
	tkm TIF	1.144.500	1.377.700
	TREMOVE / TIF tkm	1,75%	1,60%
busses & coaches (table 3.5.6)	pkm TREMOVE	382.200	409.471
	pkm TIF	382.200	410.100
	TREMOVE / TIF pkm	0,00%	-0,15%
tram+metro (table 3.5.7)	pkm TREMOVE	47.432	47.306
	pkm TIF	41.390	46.180
	TREMOVE / TIF pkm	14,60%	2,44%
railways passengers (table 3.5.8)	pkm TREMOVE	273.448	300.938
	pkm TIF	273.500	304.300
	TREMOVE / TIF pkm	-0,02%	-1,10%
railways freight (table 3.4.7)	tkm TREMOVE	220.100	244.218
	tkm TIF	220.900	249.800
	TREMOVE / TIF tkm	-0,36%	-2,23%
iww (table 3.4.8)	tkm TREMOVE	113.600	124.495
	tkm TIF	113.600	124.600
	TREMOVE / TIF tkm	0,00%	-0,08%
Total Sum of pkm TREMOVE		4.337.740	4.634.985
Total Sum of pkm TIF		4.306.650	4.645.640
Total Sum of TREMOVE / TIF pkm		0,72%	-0,23%
Total Sum of tkm TREMOVE		1.498.222	1.768.432
Total Sum of tkm TIF		1.479.000	1.752.100
Total Sum of TREMOVE / TIF tkm		1,30%	0,93%

[118] European Commission Directorate-General for Energy and Transport. *European Union Energy and Transport in Figures. Statistical Pocketbook 2003.*

In this table it can be seen that for car, two-wheelers, heavy trucks, buses/coaches, passenger and freight rail and inland waterway transport TREMOVE is consistent with the pocketbook (albeit that we could not avoid that at some instances some small differences ~1% occur). For tram and metro differences tend to be somewhat larger.

Some remarks:

- TIF does not report *air transport* activity on the same basis as TREMOVE does. TIF has some figures about airline and airport activities. TREMOVE models the yearly number of passenger-km per country, including through traffic.
- TIF does not include truck activity below 3,5 tonnes gross vehicle weight i.e. *LDVs*. It may or may not include some of them in the car passenger-km totals depending upon the definitions used in each country when supplying data to Eurostat, but we do not know for most countries whether this was done or not. We have therefore treated TIF as *not* containing LDVs for either freight or passenger.
- Note that slow traffic is not included in the pocketbook statistics, though they are in TREMOVE.

9.2 Comparison with RAINS

The next table shows the comparison of the TREMOVE baseline emissions (version 2.2, 3 December 2004) with the RAINS baseline (version November 2004). A comparison of the transport volumes could not be given, as the RAINS transport volumes are not available at the moment that this report was written.

Table 60: Comparison TREMOVE – RAINS for EU15 (fuel consumption in PJ/year)

fuel type	RAINS vehicle category		2000	2005	2010	2015	2020
CNG	cars and LDV's (non-GDI)	FC TREMOVE					
		FC RAINS	15,54	16,86	16,13	15,49	15,68
		TREMOVE / RAINS					
	HDV and busses	FC TREMOVE		0,00	0,00	0,00	0,00
		FC RAINS		0,16	0,19	0,32	0,41
		TREMOVE / RAINS	-100,00%	-99,99%	-99,98%	-99,89%	-99,86%
CNG Sum of FC TREMOVE				0,00	0,00	0,00	0,00
CNG Sum of FC RAINS			15,54	17,02	16,32	15,81	16,09
CNG Sum of TREMOVE / RAINS			-100,00%	-100,00%	-100,00%	-99,99%	-99,99%
diesel	cars and LDV's (non-GDI)	FC TREMOVE	1.854,69	2.188,22	2.394,91	2.531,89	2.670,25
		FC RAINS	2.520,11	2.705,10	2.707,04	2.649,88	2.688,39
		TREMOVE / RAINS	-26,40%	-19,11%	-11,53%	-4,45%	-0,67%
	HDV and busses	FC TREMOVE	2.659,44	2.886,26	3.113,66	3.416,18	3.817,66
		FC RAINS	2.962,21	3.480,64	4.098,81	4.646,86	5.063,71
		TREMOVE / RAINS	-10,22%	-17,08%	-24,04%	-26,48%	-24,61%
diesel Sum of FC TREMOVE			4.514,13	5.074,48	5.508,57	5.948,08	6.487,90
diesel Sum of FC RAINS			5.482,32	6.185,74	6.805,85	7.296,74	7.752,10
diesel Sum of TREMOVE / RAINS			-17,66%	-17,96%	-19,06%	-18,48%	-16,31%
gasoline	cars and LDV's (non-GDI)	FC TREMOVE	5.291,82	4.979,97	4.539,64	4.339,95	4.400,11
		FC RAINS	4.725,27	5.058,16	5.049,57	4.928,07	5.036,82

fuel type	RAINS vehicle category		2000	2005	2010	2015	2020
		TREMOVE / RAINS	11,99%	-1,55%	-10,10%	-11,93%	-12,64%
	HDV and busses	FC TREMOVE					
		FC RAINS	0,31	0,31	0,31	0,31	0,31
		TREMOVE / RAINS					
	motorcycles	FC TREMOVE	134,87	133,34	126,62	119,83	112,57
		FC RAINS	60,84	69,08	74,82	80,64	81,26
		TREMOVE / RAINS	121,68%	93,03%	69,23%	48,60%	38,52%
	2-stroke moto's and cars	FC TREMOVE					
		FC RAINS	38,52	37,87	37,86	37,94	38,03
		TREMOVE / RAINS					
gasoline Sum of FC TREMOVE			5.426,69	5.113,31	4.666,26	4.459,78	4.512,68
gasoline Sum of FC RAINS			4.824,94	5.165,42	5.162,56	5.046,96	5.156,42
gasoline Sum of TREMOVE / RAINS			12,47%	-1,01%	-9,61%	-11,63%	-12,48%
LPG	cars and LDV's (non-GDI)	FC TREMOVE	112,16	98,81	82,88	71,34	64,58
		FC RAINS	110,50	133,26	128,94	119,69	125,11
		TREMOVE / RAINS	1,50%	-25,85%	-35,72%	-40,39%	-48,38%
	HDV and busses	FC TREMOVE					
		FC RAINS	4,45	7,05	8,14	8,96	9,74
		TREMOVE / RAINS					
LPG Sum of FC TREMOVE			112,16	98,81	82,88	71,34	64,58
LPG Sum of FC RAINS			114,95	140,31	137,08	128,65	134,85
LPG Sum of TREMOVE / RAINS			-2,43%	-29,58%	-39,54%	-44,54%	-52,11%
hydrogen	cars and LDV's (non-GDI)	FC TREMOVE					
		FC RAINS		1,09	1,33	2,80	10,91
		TREMOVE / RAINS					
	HDV and busses	FC TREMOVE					
		FC RAINS		1,42	1,59	4,88	6,80
		TREMOVE / RAINS					
hydrogen Sum of FC TREMOVE							
hydrogen Sum of FC RAINS				2,51	2,92	7,68	17,71
hydrogen Sum of TREMOVE / RAINS							
Total Sum of FC TREMOVE			10.052,97	10.286,61	10.257,71	10.479,21	11.065,16
Total Sum of FC RAINS			10.437,75	11.511,00	12.124,73	12.495,84	13.077,17
Total Sum of TREMOVE / RAINS			-3,69%	-10,64%	-15,40%	-16,14%	-15,39%

The conversion of TREMOVE fuel consumption from tonnes of fuel to PetaJoule (PJ = 10^{12} Joule) has been made with the coefficients below:

gasoline:	0,00004480
diesel:	0,00004333
kerosene:	0,000046188
CNG:	0,00003997
ship gasoil:	0,000045612
LPG:	0,00004731

The TREMOVE total road fuel consumption figure is only 3,69 % below the RAINS figure for 2000.

We have to note however that, though the EU15 average is within 3,69% of RAINS, for a significant number of individual countries the difference is significantly larger. For some countries, the reasons for this divergences clearly are “tank tourism” phenomena. E.g. for Luxemburg the fuel consumption in TREMOVE (based on kms driven in Luxemburg) are 80% below the fuel consumption figures in

RAINS (based on fuel sales). In Austria there is a -20% difference, which is in line with Austrian sources.

For some other countries we could not find obvious reasons for the difference.
TREMOVE is consistent with Transport in Figures (see §9.1); and thus - as a first proxy - differences between countries in total fuel consumption are in line with the pocketbook differences in total ton and passenger kilometres between countries.

Due to differences in modal splits and fleet compositions the average fuel consumption factors per ton-km and passenger-km in TREMOVE are not completely equal in all countries (see Table 55), but the deviations are not very high.

10 Running the model software

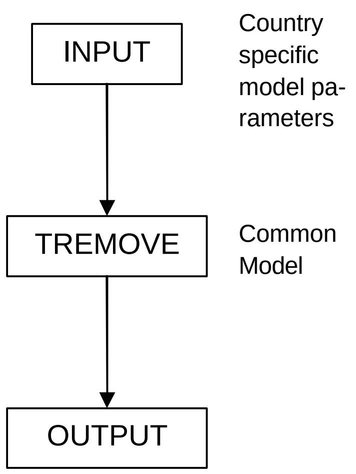
10.1 Introduction

In this chapter an overview is given of important aspects related to the software used in building the TREMOVE model. The language GAMS is used to implement the model. GAMS is short for "General Algebraic Modelling System" and is particularly well suited for doing simulations that involve large scale non-linear optimisation problems, for which the language offers a high level way of describing and solving. However, this chapter is not intended to go into the details of the language – a GAMS tutorial or user guide[119] is much more suited for this purpose – but rather to elaborate on some conceptual issues, in order to make it very easy to understand the TREMOVE model for a reader with a minimal background in the GAMS language.

10.2 Common model for all countries

Contrary to the previous TREMOVE model (version 1.3a), a common model is used for all countries. That is, one piece of software is written to serve all TREMOVE simulations. As a consequence, modification or corrections to the model are done at only one location, which brings the great advantage of guaranteed consistency between the different countries. This common model is executed by feeding it country-specific (exogenous) parameters (see Figure 45).

Figure 45 : A single model is run with country specific parameters.



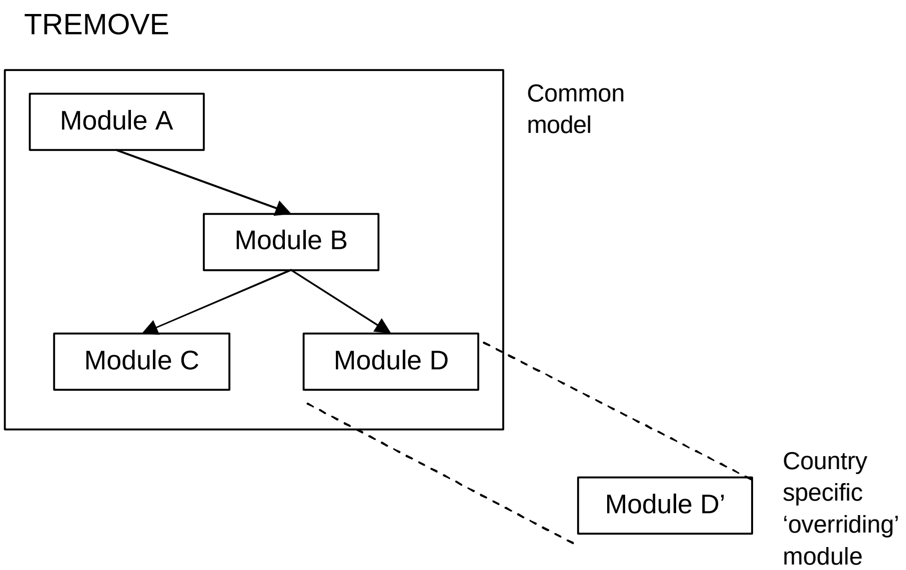
[119] Documents describing the GAMS language (including a tutorial and user guide) can be found at www.gams.com.

10.3 Modular structure

The common TREMOVE module does no longer consist of one long continuous series of software instructions, but instead is broken into several smaller pieces, called *modules*. Each module captures a single coherent piece of model behaviour. A modular structure offers a number of advantages:

- software conceptual structure is emphasised, thereby improving readability;
- the same module can be used at different locations, thus avoiding to write the same lines of code more than once and lowering the probability of making mistakes;
- when the common model is subject to minor changes for a specific country, necessary modifications can be restricted to one or more modules that are related to the alternative model behaviour, leaving the rest of the model unaltered. The module from the common model is said to be *overridden* by that of a specific country (see Figure 46).[120]

Figure 46 : Country specific TREMOVE change by overriding limited number of modules.



10.4 Special case: the demand module

Normally, calling one module from within another is very straightforward: a special command (i.e. the GAMS `$include` or `$batinclude` command[121]) ensures that the code of a called module is inserted at the location where the call is made. The whole process takes place within one and the same program, which makes the exchange of data between modules very simple.

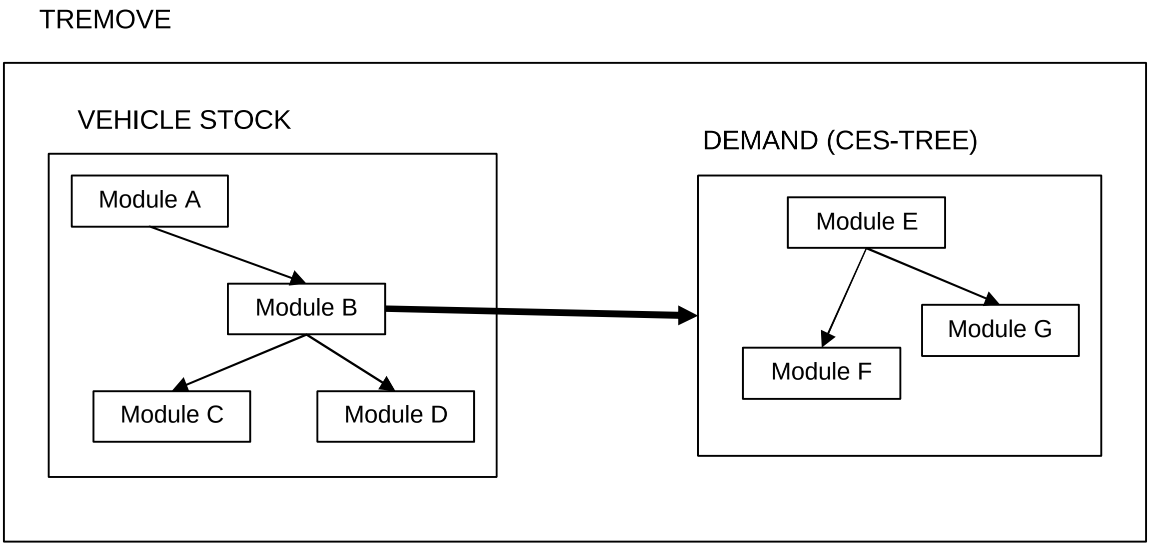
There is, however, one module that is called in a totally different manner. As can be seen from Figure 47, this is the *demand module*, which implements the CES tree, necessary for calculating price effects on transport demand. Actually, the demand module is not a module in the sense of those described above, but a full-fledged GAMS program on its own, itself consisting of different smaller 'normal'

[120] This is the case, for example, for Greece which offers its own version of `Logit_Share.gms`, the module where the calculation of vehicle logit shares takes place.

[121] This kind of modularisation is normally provided in programming languages through functions or procedures. Unfortunately, GAMS does not support this mechanism. The much more primitive `$include` and `$batinclude` constructs offer the only alternative.

modules. This has two important consequences: First, the `$include` and `$batinclude` commands are not suitable for calling the demand module (instead the special `execute` GAMS command is needed) and secondly, because the calling module and demand module are no longer in the same program, considerable care must be taken for data exchange with the demand module.[122]

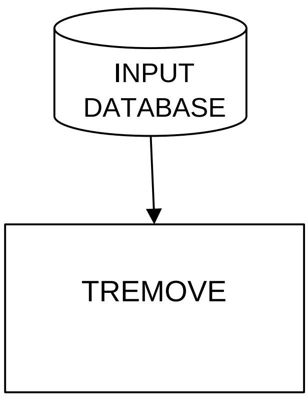
Figure 47 : Call to Demand Module (thick arrow) is different from calling other modules.



10.5 Input database

All exogenous TREMOVE model data is stored in a single MS Access database 'TREMOVE Input.mdb' (Figure 48).

Figure 48 : TREMOVE input database



The model data consists of *parameters* (values, e.g. 'base year stock') and *sets* (acting as dimensions for parameters, e.g. 'country', 'vehicle type' and 'age' are sets necessary for defining parameter 'base year stock'). Each set is defined as a separate table in the database (see Table 61).

[122] Data exchange is handled by using GAMS GDX facilities, in particular through the `execute_load` and `execute_unload` commands.

Table 61 : Selected model sets.

Model Set	Description
CAT	*Road vehicle categories*
COUNTRY	*Model countries*
IWVEHFULL	*Inland waterway vessel types*
N	*Road vehicle age*
POLLUTANT	*Emitted pollutants*
T	*Model years*
TECHFULL	*Road vehicle engine technologies*
TRAINFULL	*Train types*
VEHFULL	*Road vehicle types*

This is not the case for parameters: parameters with similar dimensions are grouped in a single table (e.g. all parameters with dimensions ‘country’, ‘vehicle type’ and ‘year’ are grouped in table ‘T_VEHICLE_PARAMETER’). All tables containing parameters have a ‘_PARAMETER’ extension.

The important *table ‘PARAMETER_NAME’ acts as an index*. It contains a full inventory of model parameters along with a description and the name of the corresponding database table. An overview of some important parameters is given in Table 62.

Table 62 : Selected model parameters.

Description	Parameter Name	DB Table Name
Base year Road vehicle stock	RSTNBY	T_VEHICLE_PARAMETER
Base year Train stock	TSTBY	TRAIN_FRPA_PARAMETER
Technology distribution matrix – road	TECHMX	T_VEHICLE_TECH_PARAMETER

10.6 Executing the model

To run the TREMOVE model for a specific country (e.g. Germany) do the following:

1. Open a project in the 'Run' folder
2. Execute 'Run.gms' with option 'idir=..\Input;"..\Input\DE";"..\Vehicle Stock Module"'

To reproduce the output for Germany do:

3. Same as step 2 but with additional option 's=save_DE'
4. Execute 'Output_GDX.gms' with options 'r=save_DE'
5. The file 'output.gdx' will contain the output and can be read with 'GDXViewer' or converted to Access with 'Gdx2access' (both tools are included in the free GAMS WTOOLS package).

The TREMOVE model is organised in several subfolders. They are:

- *Vehicle Stock Module*: Contains the gams code of the vehicle stock module of the TREMOVE II model. The model is executed from within folder 'Run' (see below).

- *Demand Module*: Contains the gams code of the demand module of the TREMOVE II model. Country specific demand data is stored in the 'Country Input' subfolders.

- *Run*: Home directory for the gams project file and files 'Run.gms' and 'Output_GDX.gms' which should be executed to run the TREMOVE II model and get some output (see above).

- *Input*: Contains one subdirectory per country in which country specific model specifications (overriding modules) and input files are stored. Country independent input is stored in the root directory.

- *IWW Shares and Load Factors Module*: Gams model for pre-processing inland waterway related input data. See Readme.txt inside the folder for more information.

- *Access DB*: Contains input Access database. Can be converted to GAMS ‘.inc’-files by using 'Build_GAMS_input.bat' (for country independent files) and 'Build_GAMS_Input_Country.bat' (for country dependent input) in 'Access-GAMS Conversion' subfolder.

11 Model output structure

This section contains a short explanation of the geographic structure, the time horizon, trip purposes, vehicle classes and emissions covered by TREMOVE.

11.1.1 Summarising table

Table 63: TREMOVE disaggregation levels

LEVELS OF DISAGGREGATION	#
COUNTRY (or SEA)	**21** AT, BE, CH, CZ, DE, DK, ES, FI, FR, GR, HU, IT, IE, LU, NL, NO, PL, PT, SE, SI, UK **8** North Sea, Irish Sea, English Channel, Black Sea, Mediterranean, Baltic Sea, North East Atlantic Ocean, Rest of EMEP
TRIP PURPOSE	**6** commuting trip, non-working trip, business trip, bulk freight transport, cargo freight transport, unitised freight transport
TRIP DISTANCE	**3** urban, short distance, long distance
REGION	**3** metropolitan city, other cities, non-urban
NETWORK	**6** urban road, non-urban road, motorway, rail, inland waterway, air
PERIOD	**2** [PEAK, OFFPEAK]
VEHICLE CATEGORY	**15** maritime ship, plane, inland ship, passenger train, freight train, metro/tram, coach, bus, heavy duty vehicle, light duty vehicle, motorcycle, moped, big/medium car, small car, slow
FUEL TYPE	**11** diesel, gasoline, LPG, CNG, electric, train diesel, ship gasoil, kerosine, maritime gas oil, maritime diesel oil, maritime residual oil
VEHICLE TYPE	**54 land + 27 sea** (including fuel types) slow: **0** small car: **4** big/medium car: **9** moped: **1** motorcycle: **4** light duty vehicle: **2** heavy duty vehicle: **4** bus: **2** coach: **1** metro/tram: **2** passenger train: **5** freight train: **4** inland ship: **21** plane: **5** maritime ship: **27**
VEHICLE TECHNOLOGY	.. (a lot) ..
VEHICLE AGE	**60** 0 .. 59
YEAR	**26** 1995 .. 2020

VALUES	**UNIT**
PKM	million passenger km / year
TKM	million ton km / year
VKM	million vehicle km / year
VEHICLES	vehicles
EMISSIONS: C6H6, CH4, CO, CO2, N2O, NMVOC, NOx, PM, SO2, VOC,	ton / year

gasoline PM, non-exhaust PM	
FUEL CONSUMTION: FC	ton / year
ENERGY CONSUMPTION	kWh / year

DERIVED VALUES	**UNIT**
APPARENT EMMISON FACTORS	g / vkm, g / pkm or g / tkm
OTHER VALUES COULD BE CREATED ON DEMAND …	

11.1.2 Country and sea coverage

TREMOVE covers 21 countries: the EU15 region, Switzerland, Norway, Czech Republic, Hungary, Poland and Slovenia. The 4 new Member States are selected on the basis of data availability.
For these 21 countries, all land transport has been modelled as well as maritime port transport.

Table 64: Countries covered by TREMOVE

AT	Austria	FI	Finland	NL	The Netherlands
BE	Belgium	FR	France	NO	Norway
CH	Switzerland	GR	Greece	PL	Poland
CZ	Czech Republic	HU	Hungary	PT	Portugal
DE	Germany	IE	Ireland	SE	Sweden
DK	Denmark	IT	Italy	SI	Slovenia
ES	Spain	LU	Luxemburg	UK	United Kingdom

The model structures allows an easy update to EU25, when data from Slovakia, Estonia, Latvia, Lithuania, Malta and Cyprus becomes available.

The maritime area consists of 8 sea regions, chosen on the basis of the ENTEC report[123]
The maritime area covers maritime ships (excluding military ships and fishing vessels) as well as passenger ferries.

Table 65: Maritime areas covered by TREMOVE

AO	North East Atlantic Ocean	IS	Irish Sea
BA	Baltic Sea	MS	Mediterranean
BL	Black Sea	NS	North Sea
EC	English Channel	RE	Rest of EMEP

11.1.3 Trip purpose

To improve the behavioural response of the model, passenger and freight transport demand is differentiated by trip purpose and by category of freight respectively.
- Passenger transport: business, commuting and non-working trips.
- Freight transport: bulk goods, unitised freight and cargo freight.

11.1.4 Trip distance and region

Total transport flows and emissions in each country are allocated to 3 model regions: one metropolitan city, an aggregate of all other cities and an aggregate of all non-urban areas.

[123] ENTEC, *Quantification of emissions from ships associated with ship movements between ports in the European Community*. Final report to the European Commission, July 2002.

In addition, transport in non-urban areas is split up into short (- 500 km) and long (+ 500 km) distance trips.

11.1.5 Network

The network type is directly related to the vehicle category.

Fro road transport, 4 road types are considered: urban roads (both in the metropolitan area and the “other cities” region), non-urban roads and motorways. All these road types have a different congestion behaviour, and thus a different speed-flow relationship. The model takes into account that several vehicle categories, as cars, busses, HDV’s etc. drive on the same road and influence each others speed.

11.1.6 Period

Two periods have been modelled: peak and off-peak. This has been done for several purposes:

- Modelling time-of-day choices and thus a more elaborated modal choice.
- Modelling congestion (traffic jams) and Mohring effects (public transport efficiency) differently in peak and off-peak periods.
- Calculation of emissions, depending of the speeds in peak and off-peak periods.

The peak period is *approximately* 4 hours, while off-peak period takes 20 hours. More detail can be found in §3.10.6.

11.1.7 Vehicle category

The TREMOVE model covers all relevant passenger and freight transport modes:

- Passenger transport: slow modes (pedestrians and bicycles), cars (small and medium/big), mopeds, motorcycles, busses, metro/tram, passenger trains, planes, and ferries.
- Freight transport: HDV’s, freight trains, inland ships, and maritime vessels.

In the vehicle stock module, the vehicle categories are further detailed into vehicle types, fuel types and vehicle technologies. A full list can be found in the chapter on vehicle stock modelling (§4).

11.1.8 Pollutants

Emissions of all modes are computed, which involves detailed modelling of vehicle stock turnover and emission factors for all road and non-road vehicles. Existing as well as new vehicle technologies are included in the model.

As the TREMOVE model will be used in the context of the CAFE and the ECCP programmes, conventional as well as greenhouse gas pollutants will be considered. Within the conventional pollutants category, specific attention has been devoted to fine particulates (PM10 as well as the finer particulates). Not only exhaust emissions, but also non-exhaust emissions (i.e. evaporative emissions, wear of tyres and brakes) and emissions during fuel/electricity production have been taken into account.