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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

LONG-RUN IMPACTS OF POLICY PACKAGES ON MOBILITY IN BELGIUM

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I. De Vlieger, I. Mayeres, H. Michiels, L. Schrooten, M. Vanhulsel, D. Gusbin, B. Hoornaert, M. Vandresse, A. Van Steenbergen, D. Dewaele, B. Jourquin

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Transport and Mobility

FINAL REPORT

LONG-RUN IMPACTS OF POLICY PACKAGES ON MOBILITY IN BELGIUM

LIMOBEL

SD/TM/01

Promotors

Ina De Vlieger – Inge Mayeres
VITO
Boeretang 200 - 2400 Mol

Marie Vandresse
Federal Planning Bureau
Kunstlaan 47/49 - 1000 Brussels

Bart Jourquin
FUCaM
Chaussée de Binche 151 - 7000 Mons

Authors

Ina De Vlieger, Inge Mayeres, Hans Michiels, Liesbeth Schrooten,
Marlies Vanhulsel (VITO)
Dominique Gusbin, Bruno Hoornaert, Marie Vandresse,
Alex Van Steenbergen (FPB)
Davy Dewaele, Bart Jourquin (FUCaM)

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Published in 2011 by the Belgian Science Policy
Avenue Louise 231
Louizalaan 231
B-1050 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12
http://www.belspo.be

Contact person: Georges Jamart
+32 (0)2 238 36 90

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LIST OF ABBREVIATIONS

BAU	Business-as-usual
CGE	Computable general equilibrium
CNG	Compressed natural gas
CR function	Concentration-response function
DCW	Digital chart of the world
GDP	Gross domestic product
HDF	Heavy duty freight vehicle
HDP	Heavy duty passenger vehicle
HDV	Heavy duty vehicle
IWW	Inland waterways
kEUR	Kilo EUR = 10^3 EUR
LDV	Light duty vehicle
LPG	Liquified petroleum gas
MEC	Marginal external costs
MEUR	Million EUR = 10^6 EUR
NST/R	Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée
NUTS	Nomenclature of territorial units for statistics
O-D	Origin-Destination
PIT	Personal income tax
SAM	Social accounting matrix
SUT	Supply and Use table
VA	Value added
VAT	Value added tax

LIST OF SYMBOLS

CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
N_2O	Nitrous oxide
NH_3	Ammonia
$Nitr_{2.5}$	Nitrate aerosols with an aerodynamic diameter ≤ 2.5µm
NMVOC	Non-methane volatile organic compounds
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
Pb	Lead
PM_{10}	Particulate matter with an aerodynamic diameter ≤ 10µm
PM_{10} pr	Primary particulate matter with an aerodynamic diameter ≤ 10µm
$PM_{2.5}$	Particulate matter with an aerodynamic diameter ≤ 2.5µm
$PM_{2.5}$ pr	Primary particulate matter with an aerodynamic diameter ≤ 2.5µm
PM_{coarse}	Particulate matter with an aerodynamic diameter 2.5-10µm
SO_2	Sulphur dioxide
$Sulph_{2.5}$	Sulphate aerosols with an aerodynamic diameter ≤ 2.5µm
TSP	Total suspended particles

1. SUMMARY

1.1. Context and aims

The aim of the LIMOBEL project was to develop a framework that can be used to

- make long-term projections of transport in Belgium;
- analyse the long-run mobility impacts of policy packages in Belgium, including pricing instruments, infrastructure changes and regulation;
- to perform a social cost benefit analysis of these policy measures.

LIMOBEL deals with three priority research areas that are interrelated: transport and mobility, energy and environmental issues. It is well known that, while generating many benefits, transport use also causes many problems, of which congestion, accidents and environmental costs are the most important. These problems call for government intervention in order to arrive at a more sustainable transport system.

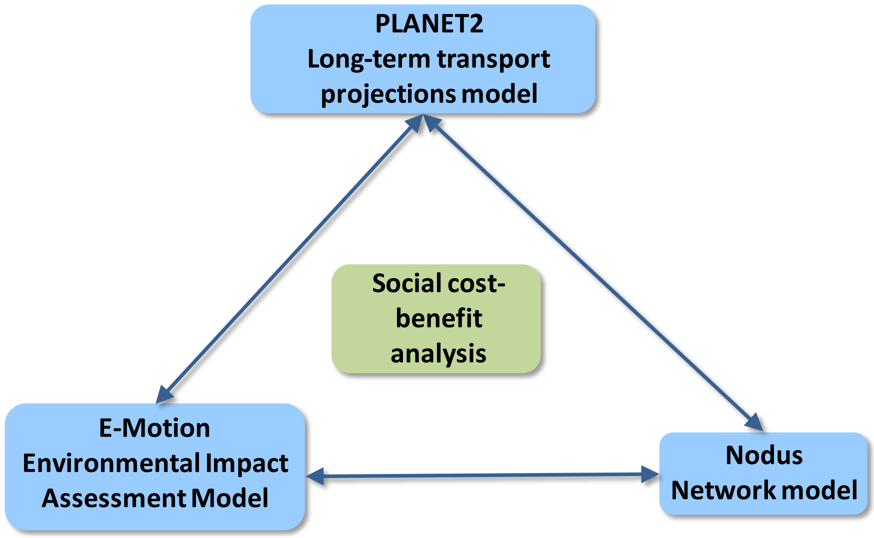
1.2. The LIMOBEL approaches

LIMOBEL uses two types of approaches to tackle these issues. The first approach is partial equilibrium in nature, in the sense that it focuses on the transport sector. It is dynamic and has a long-term time horizon (up to 2030). Three existing models were developed further and linked to each other.

- The PLANET model is a model for long-term transport projections. The existing version is extended by including a new vehicle stock module and the updated emission factors and environmental costs computed by the environmental impact assessment model.
- The NODUS model has been extended in order to cover both passenger and freight transport.
- The E-Motion model is an environmental impact assessment model that consists of an emission model for road, railway and shipping traffic and of an environmental cost model.

The three models are linked to each other, but they are not solved simultaneously. However, various inputs and outputs are exchanged between them (Figure 1).

The links between the LIMOBEL model components



The second approach considers the two-way interaction between the transport sector and the rest of the economy, and is therefore general equilibrium in nature. For this we use a computable general equilibrium model for Belgium and its three regions. In contrast to the first approach, this model is static and only provides simulations for one year. However, it allows us to consider the wider economic impacts of transport policies.

Together, these two approaches make it possible to meet our research objectives in the following ways:

- They enable us to analyse the interaction between mobility and environmental problems, by explicitly considering the environmental costs of transport and by considering the impact of policy measures on different transport related problems (congestion, environmental problems, energy use) and by not concentrating on only one problem.
- It is possible to consider policy packages, consisting of different instruments (pricing, regulation, infrastructure measures) that may address different transport problems. Complementarities and synergies between these instruments can be analysed.
- The first approach has a time horizon of up to 2030. It therefore produces a long term view of sustainable mobility and the mobility policies necessary to reach it. This time horizon also makes the project relevant for the negotiations about greenhouse emissions beyond the Kyoto protocol.
- The computable general equilibrium model used in the second approach allows us to analyse policy packages that do not only contain transport instruments, but also more general instruments (non-transport taxes, transfers) to ensure budget neutrality. The policy instruments may consist of both federal and regional measures. The model considers the potential and limitations of these measures in terms of their impact on economic performance and on welfare.

– By considering the economic evolution at the regional level and by considering a network model the project explicitly takes into account the spatial dimension.

As such, the project presents an interdisciplinary approach, with contributions from macroeconomics, public economics, transport economics and environmental impact assessment.

1.3. Lessons from and for modelling

An important lesson is that the development of the LIMOBEL tools was complex but that we arrived at a usable modelling framework. In some cases, however, we had to downsize our ambitions somewhat. This gives rise to opportunities for further development. Another conclusion that holds for all of the models is that in order to keep going in this direction, further efforts by statistical offices to gather data and to maintain data up-to-date are needed.

1.4. Policy conclusions

1.4.1. Lessons learned from the historical analysis

For the historic years the E-Motion model finds that CO_2 emissions by the Belgian *car fleet* fell by 2.6% in the period 2000-2008, with the largest reduction taking place between 2007 and 2008. The evolution is the result of the increase in the total number of cars (leading to an increase of CO_2 emissions by 9.4%), the switch from gasoline to diesel cars and the changes in the annual mileage per car (-7.1%), the increasing share of smaller cars (-1.7%) and the improvement in fuel efficiency over time (-3.3%).

The fuel efficiency of *new* passenger cars in Belgium has improved between 2002 and 2009, both for diesel and petrol cars. The down-sizing of the engines is responsible for part of this improvement. The reduction in energy consumption is however more pronounced for petrol than for diesel cars. Between 2004 and 2007 there was only a small reduction in the fuel consumption of diesel cars. This is due to the rising sales figures of diesel cars with large cylinder capacities. The stronger decrease after 2007 can be explained by the increase in sales figures of small diesel cars. Furthermore, there is an increase in sales of green cars. These include hybrid vehicles and low CO_2-emitting petrol and diesel fuelled vehicles (by e.g. improved aerodynamics, start-stop systems, lower rolling resistance). The evolution was encouraged by several policy measures: the direct discount for new energy efficient diesel cars and the introduction in 2007 of the CO_2 emissions as a determinant for the tax deductibility of company cars. Also European policy towards low CO_2-emitting cars pulls in the right directions.

CO_2 emissions can directly be deduced from the petrol and diesel consumption figures. So, the *average CO_2 emissions of new cars* also drop between 2002 and 2009. In 2009 the average CO_2 emission from new passenger cars in Belgium was 144.3 g/km. The

European directive EC/443/2009 enforces an average for the whole of the EU of 130 gCO_2/km by 2015. The evolution of CO_2 emissions from new cars shows it will possibly not be reached by 2015 in Belgium. But, if CO_2 emissions from new cars continue to follow the evolution of the last three years (2007-2009), it would be easy to meet the objective for Belgium. At this stage it is however not yet clear whether the recent evolutions are structural or due to the economic crisis.

1.4.2. Lessons learned from the LIMOBEL reference scenario

The new version of the PLANET model was used in combination with the environmental impact assessment model and the NODUS model to update the reference scenario for long-term transport and mobility development in Belgium.

The reference scenario projects a further growth between 2005 and 2030 of passenger and freight transport by respectively 31% and 60%. In combination with the continuing dominance of the road modes, this would further deteriorate traffic conditions in Belgium, as reflected in a fall in average speed by 31% in the peak period and 17% in the off-peak period. As a result, the currently observed discrepancy between taxes and marginal external costs is projected to worsen over time. As concerns the evolution of the direct emissions related to the transport activity, the implementation of environmental policies in the reference scenario will be successful in reducing emissions of the traditional air pollutants (CO, $PM_{2.5}$, NMVOC, NO_x and SO_2), even when taking into account the growth in transport. Greenhouse gas emissions will increase, however, by 3% between 2005 and 2030. The consumption of fuel for the transport activity increases by 14.4% in the same period.

The LIMOBEL project performed detailed calculations to update the estimates of the marginal external costs per tonne of $PM_{2.5}$ and NO_x emissions. For the other pollutants a literature review was made. The LIMOBEL calculations for future years take into account the change in the background concentrations and the demographic projections. For the $PM_{2.5}$ emissions the marginal external costs are positive and increasing over time. The increase can be explained almost completely by the demographic evolution. In the case of the NO_x emissions, we find a marginal external benefit rather than a cost in 2007 because higher NO_x emissions lead to a reduction of the concentrations of sulphate aerosols and ozone. In 2020 and 2030 this positive effect is no longer large enough to compensate for the damages caused by the higher concentrations of nitrate aerosols. In those years the NO_x emissions are therefore associated with a marginal external cost.

When we combine these estimates with the projected evolution of the emissions of the reference scenario, we can calculate the total environmental costs related to transport in Belgium. They are projected to be 94% higher in 2030 than in 2010, if a central value for the damage of greenhouse gas emissions is used, and this in spite of the fall in the emissions of all pollutants except the greenhouse gases. The growth is due to the increase in damage costs over time (due to changes in background concentrations, population and

GDP per capita). The direct environmental costs account for 60% to 75% of the total environmental costs. The difference between the two consists of the indirect environmental costs that are related to the production and transport of the fuels and to the production of electricity used by rail transport. The share of the environmental costs of freight transport is projected to grow between 2010 and 2030 (from 26% to 33%). Over time greenhouse gas emissions will account for an increasing share of the environmental costs (from 53% in 2010 to 69% in 2030).

1.4.3. Lessons learned from the LIMOBEL policy simulations.

Up to now the combination of models has been used to simulate the impacts of two policy scenarios.

The first simulation consists of a *kilometre charge on heavy duty vehicles* only, while in the second one the charge is also levied on *light duty vehicles and cars*. If the objective of charge is to reduce congestion and environmental costs, the results show that charging heavy duty vehicles alone does not appear to be efficient. While leading to a modal shift toward light duty vehicles, barges and trains, the shift towards light duty vehicles is dominant, which leads to an increase in congestion (due to the lower load capacity of light duty vehicles). The effect on total emissions is close to zero and the environmental damage of transport even rises (due to the increase in light duty vehicles).

To avoid this problem, charging heavy and light duty vehicles simultaneously is necessary. Furthermore, bearing in mind the importance of passenger road transport, charging cars too, as is done in the second simulation, leads to a significant improvement of congestion, more particularly in the peak period, and of the emissions (direct and indirect) generated by transport.

Concerning welfare, the analysis shows also the second simulation exercise leads to a welfare gain for society, if taxes are recycled through lower labour taxes. However, if taxes are recycled through a reduction in general taxation, the impact on welfare is negative for the levels of the kilometre charge that are considered in the simulation.

The fact that revenue recycling is an important determinant of the welfare impact of transport policies, is an important conclusion that can be drawn both from the analyses with the PLANET model and from the exercises performed with the Computable General Equilibrium model.

At this stage we are only able to present a limited number of simulations. However, the LIMOBEL framework is ready for additional simulations. A number of these simulations will be performed in the cluster project PROLIBIC, after consultation of the follow-up committee of that project.

1.5. Keywords

Long-term transport model, transport network, environmental costs, transport policies, cost-benefit analysis

2. INTRODUCTION

2.1. Aims and context

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- By considering the economic evolution at the regional level and by considering a network model the project explicitly takes into account the spatial dimension.

As such, the project presents an interdisciplinary approach, with contributions from macroeconomics, public economics, transport economics and environmental impact assessment.

2.2. Structure of the report

The structure of this report is as follows. Chapter 3 presents the modelling framework for the long-term analysis. It discusses the set-up and methodology of the three modelling components and presents the results of two simulation exercises. Next, Chapter 4 turns to the interactions between the transport sector and the general economy. It starts with a presentation of the characteristics of the CGE model; a discussion of some simulation results follows. Chapter 5 summarises the lessons learned and the policy conclusions. The final chapters give an overview of the dissemination and valorisation activities, together with the publications that were realised in the context of the LIMOBEL framework. The report is accompanied by a number of annexes that present more detail for some of the LIMOBEL components.

3. LONG-TERM PROJECTIONS OF TRANSPORT, EMISSIONS AND ENERGY USE

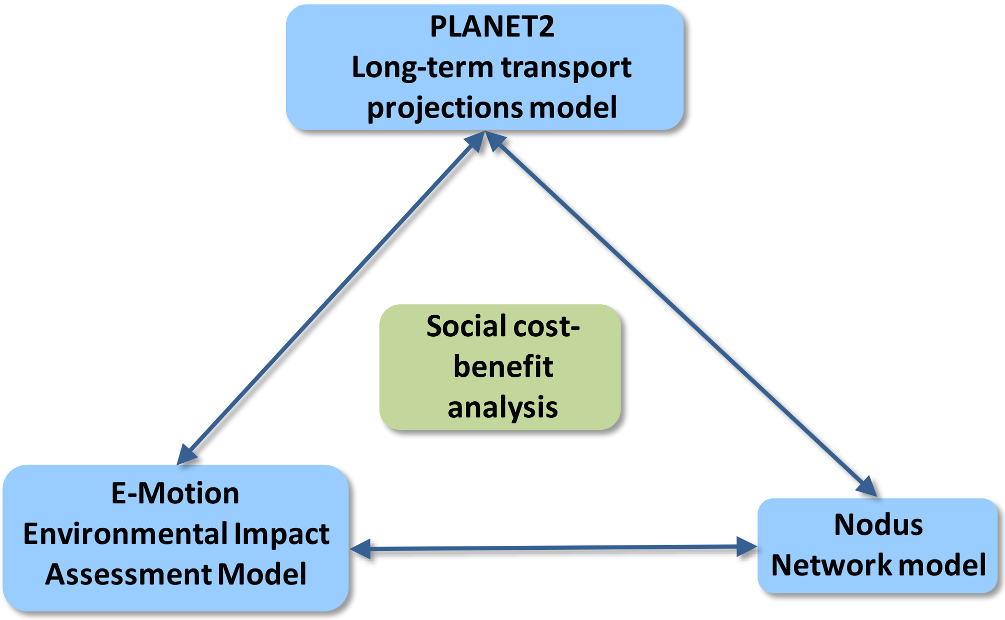
3.1. Introduction

The modelling framework for the long-term projections of transport, emissions and energy use basically uses three models:

- PLANET: a model for long-term transport projections;
- NODUS: a network model for passenger and freight transport;
- E-motion: an environmental impact assessment model.

The three models are linked to each other, but do not optimise simultaneously. However, various inputs and outputs are exchanged between them (Figure 1).

Figure 1: The links between the LIMOBEL model components



The aim of the PLANET-model is to construct long-term transport projections and to simulate the impacts of various policy measures. It is a partial equilibrium model for the transport sector. Starting from an exogenous economic and demographic evolution, it determines transport generation, trip distribution, modal and time choice and the composition of the vehicle stock, that result from defined transport policy measures.

The aim of NODUS is to analyse the impact of pricing and infrastructure policies on the transport flows on the networks, transport costs and modal split. This requires a detailed network model with an interaction between freight and passenger transport. The network model may be fed by the changes in the origin-destination matrices determined in PLANET. PLANET also provides information on the long-term evolution of some transport cost components, such as labour, energy prices, taxes, etc.

E-Motion, the environmental impact assessment tool, consists of an emission model for road, railway, inland navigation and maritime shipping on the one hand and an external environmental cost model on the other hand. The main aim of this tool is to provide the latest know-how on fuel efficiency, emission factors and damage per tonne of emissions. This information is integrated in the PLANET model as an input to calculate the evolution of emissions and environmental damages related to transport. The results on fuel efficiency are also used as an input in the vehicle stock module of PLANET. E-Motion may take into account the outcomes of the network model concerning the number of km travelled on different routes and in different regions.

The set-up of the three models is discussed in Sections 3.2 to 3.4 Next, Section 3.4.3 discusses the results of a number of simulations.

3.2. The PLANET model

3.2.1. Overview of the PLANET model

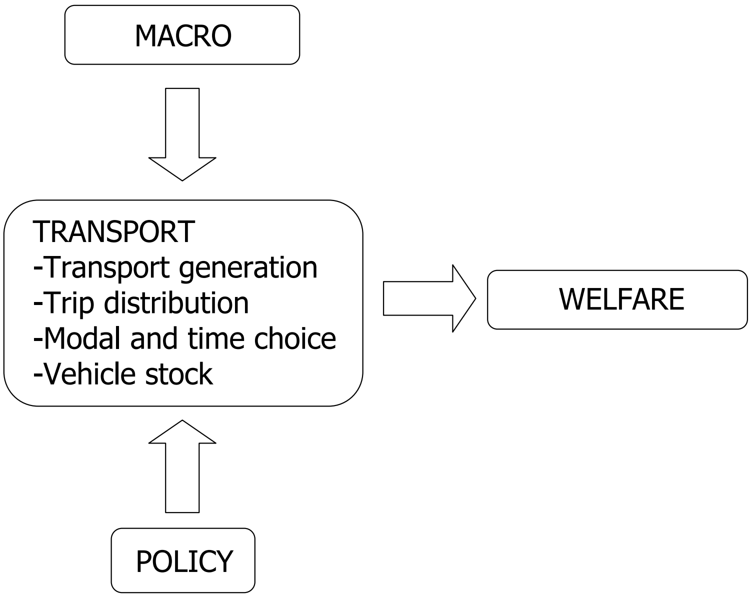
The PLANET model is a model of the Belgian Federal PLANning Bureau (developed thanks to a collaboration agreement with the SPF Mobility& Transport) that models the relationship between the Economy and Transport. The aim of the model is to produce:

– medium- and long-term projections of transport demand in Belgium, both for passenger and freight transport;
– simulations of the effects of transport policy measures;
– cost-benefit analyses of transport policy measures.

The main strengths of the model lie in the long term horizon of PLANET, the simultaneous modelling of passenger and freight transport and the welfare evaluation of policies. The effects of transport on the environment are also highlighted in the model. An implication of the strategic nature of PLANET is that it necessarily operates at a more aggregate level than some of the other models generally used in transport analysis. In this section we shortly describe the main features of the PLANET model.

The current version of PLANET (v2.0) consists of seven interrelated modules: Macro, Transport Generation, Trip Distribution, Modal and Time choice, Vehicle Stock, Welfare and Policy. The relationships between these modules are summarised in Figure 2 and Figure 3. Compared to PLANET v1.0, that is described more fully in Desmet et al. (2008), version 2.0 includes the vehicle stock module and fully integrates the updated emission factors and environmental costs associated with each type of vehicle, as calculated by the environmental impact assessment model that is presented in Section 3.4. In the PLANET model they are therefore considered as inputs.

Figure 2: The PLANET modules

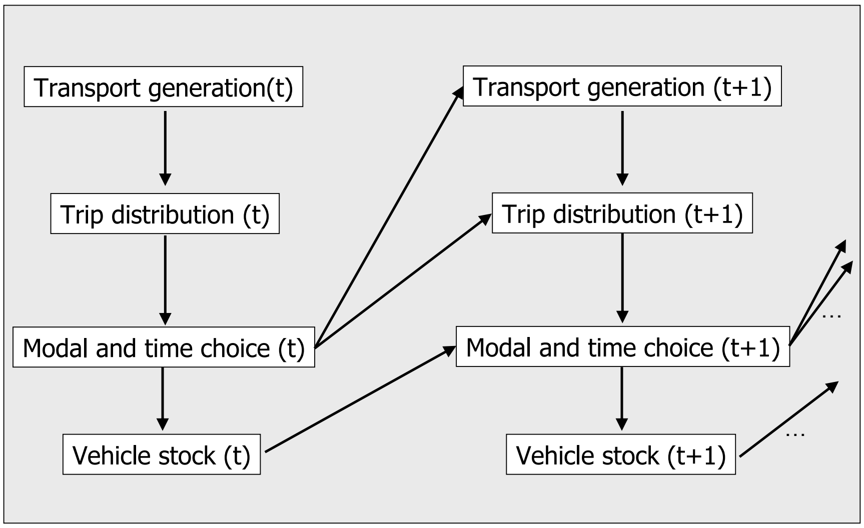


The *Macro module* provides macro-economic projections at the level of the NUTS3 zones (“arrondissementen/arrondissements”) for Belgium. This is done by spatially disaggregating results of HERMES and MALTESE, two national projection models developed by the FPB. This information is supplemented by demographic and socio-demographic projections.

The *Policy module* summarises the policy instruments that are used in the business-as-usual and alternative scenarios. These consist of transport instruments (such as fuel taxes, ownership taxes or road pricing).

The transport core of PLANET consists of four modules (see also Figure 3). The *Transport Generation module* derives the total number of commuting and school journeys produced in and attracted to each NUTS3 zone. In addition, it makes a projection of the total number of passenger trips for “other” purposes and of the total tonnes lifted for national and international freight transport. The results of this module are fed into the *Trip Distribution module* which determines the number of trips taking place between each of the zones. In the next step *the Modal and Time Choice module* derives the modes by which the trips are made and the time at which the trips take place (in the case of road transport). These choices depend on the money and time costs of the different options. Travel time for the road modes is determined endogenously, by means of the speed-flow function that gives the relationship between the average speed of the road transport modes and the road traffic levels. In the framework of the LIMOBEL project, the average speed computed in this module can be used, as an input, in the network model (NODUS) in order to evaluate the impact of a variation of the average speed on the road network. However, note that PLANET works at the national level (and thus with a national average speed), while the network model is more accurate on a geographical scale. The Modal and Time Choice module also provides information on the net government revenue obtained from transport. The *vehicle stock module* calculates the size and composition of the car stock. Its output is a full description of the car stock in every year, by vehicle type, age and (emission) technology of the vehicle. The vehicle stock is represented in the detail needed to compute transport emissions. The module is discussed further in Section 3.2.2. The integration of the vehicle stock module in PLANET allows to better capture the impact of changes in fixed and variable taxes levied on cars. Among these impacts, the effect on the environment is of particular interest.

Figure 3: The link between the TRANSPORT modules in PLANET



Some of the outcomes of the four transport modules for year *t* are assumed to influence transport demand in year *t*+1. First of all, the demand for passenger trips for “other” purposes and of tonnes lifted in Belgium by transit freight transport (determined in the Transport Generation module) depends on the average generalised cost of these transport flows in the previous year (determined in the Modal and Time Choice module). Secondly, the generalised transport costs resulting from the Modal and Time Choice module influence trip distribution in the next year. Finally, the composition of the road vehicle stock has an impact on the monetary costs of road transport in the next year.

The *Welfare module* computes the effects of transport policy measures on welfare. It produces a cost-benefit analysis of the transport policy reforms summarised in the Policy module. It takes into account the impact on the consumers, the producers, the government and environmental quality.

3.2.2. Vehicle choice

The vehicle choice module has been developed recently at the FPB (thanks to a collaboration agreement with the SPF Mobility & Transport). Its influence on the environmental impact of (transport) policies is non-negligible and of great interest. This module benefits from an update of the emission factors and the environmental costs realised by VITO in the framework of the LIMOBEL project (see Section 3.4.1). Consequently, the module is presented here in some detail. For additional information, we refer to Mayeres et al. (2010).

a. General methodology

Vehicle choice is modelled endogenously for the car stock. The general modelling principles are as follows. For each car type the vehicle stock is described by vintage and vehicle type. If $Stock_i(t,T)$ represents the vehicle stock of type *i* (diesel and gasoline car) in year *t* and of age *T*, the two basic equations are:

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

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

$Sales_i(t)$ stands for the sales of new cars of type *i* in year *t* and $Scrap_i(t,T)$ is the scrappage of vehicles of type *i* and age *T* in year *t*.

In each year *t* the stock of vehicles surviving from year *t*-1 is compared with the desired stock of vehicles needed by the transport users. If the desired stock is larger than the surviving stock, new vehicles are bought. This approach requires the determination in each year of the total *desired vehicle stock*, the number of *vehicles of each type* that is *scrapped* and the *composition of the vehicle sales*.

The model includes vehicles from age 0 until the age they are scrapped or leave the country. Any changes in ownership in between are not modelled. No separate categories are considered for new and second hand vehicles. Furthermore, at this stage, there is no distinction between cars owned by private business, government and utilities on the one hand and private cars on the other hand.

The desired vehicle stock

In order to derive the total desired vehicle stock the following approach is considered. The desired car stock is derived from the number of vehicle km (as computed in the Modal and Time Choice module), given an annual mileage per vehicle that is assumed to be constant over the years. With this hypothesis, we assume drivers do not change their driving behaviour (annual mileage) when they buy a car of another type (small, medium, big). For example, if a driver sells his big car for a small car, his annual mileage will not change. The average mileage of big cars will decrease (resp. increase) and the one of smalls car will increase (resp. decrease). Consequently, the average mileage remains constant.

The number of scrapped vehicles (per type)

Remark: In this version of the model scrappage is assumed to be exogenous

In order to know the surviving car stock in year *t* a scrappage function needs to be determined. The scrappage function is estimated for the following car types: diesel cars and gasoline cars. The scrappage rate of these vehicles is estimated according to the age of the vehicle (*T*), with a scrappage function determined by a loglogistic distribution. The following equation gives the hazard function of the loglogistic distribution which describes the rate at which cars are scrapped at age *T* given that they stay in the vehicle stock until this age.

$$h(T) = cons + \frac{\lambda\rho(\lambda T)^{\rho-1}}{1+(\lambda T)^{\rho}}$$

where *λ* and *ρ* are shape and scale parameters and *cons* is a constant term. If the value of the shape parameters (*λ*) lies between 0 and 1, the shape of the hazard function first increases and then decreases with age. The loglogistic hazard function is also concave at first, and then becomes convex. The shape of this hazard function is close to the shape of the scrappage rates for all vehicle types observed during the years 2000 to 2005[1]. The parameters *λ* and *ρ* and the constant term are estimated on the basis of data obtained from the DIV.

The DIV has provided us with time series of the age distribution of the car fleet according to fuel. The time series refer to the years 1997 to 2005 (except 1999). These data are used to calculate scrappage rates according to fuel and age for all reported years. The observed number of scrapped vehicles of age *T* is defined as the difference between the number of vehicles of age *T* in year *t* and the number of vehicles of age *T*+1 in year *t*+1. The scrappage rate is then obtained by dividing the number of scrapped vehicles per age in year *t* by the total number of vehicle of this age in the fleet during the same year.

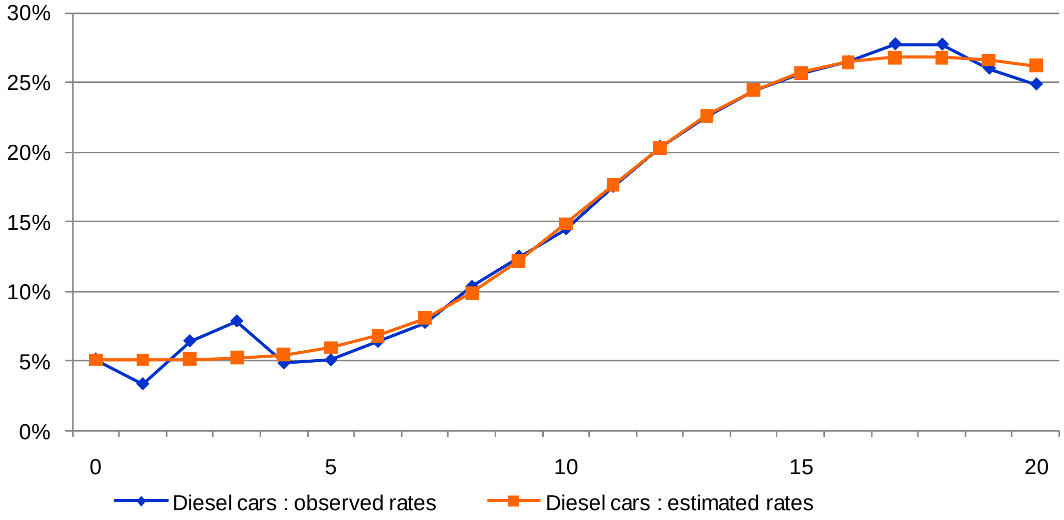
Based on the observed scrappage rates, the constant and the parameters *λ* and *ρ* of the loglogistic hazard function were estimated by means of a nonlinear least squares estimator in TSP. The estimation only takes into account vehicles of 20 years and younger. This is done because the stock after this age becomes less representative as the number of old vehicles becomes smaller and smaller[2].

Figure 4 and Figure 5 present the observed and estimated scrappage rates for the 2 vehicle types.

1 A Weibull distribution is often used to model duration data, but the shape of its hazard function -"s-shape"- does not correspond well to the shape of the observed scrappage rates.

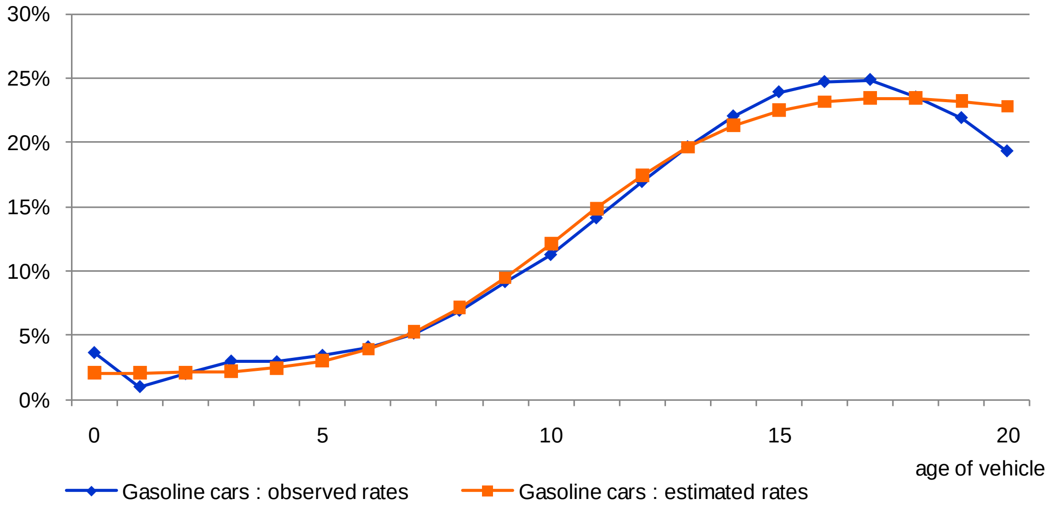
2 In the period 2000 to 2005, 96% of the car stock was between 0 to 20 years old.

Figure 4: Observed and estimated scrappage rates for diesel cars between 0 and 20 years old



Source: FPB.

Figure 5: Observed and estimated scrappage rates for gasoline cars between 0 and 20 years old



Source: FPB.

The comparison of the observed and estimated scrappage rates shows that the estimated scrappage rates are able to reflect rather well the specificities of the car fleet evolution. Nevertheless, for the 4 first years of registration, the estimated scrappage rate cannot reproduce the fluctuations of the observed scrappage rate.

The composition of the vehicle sales

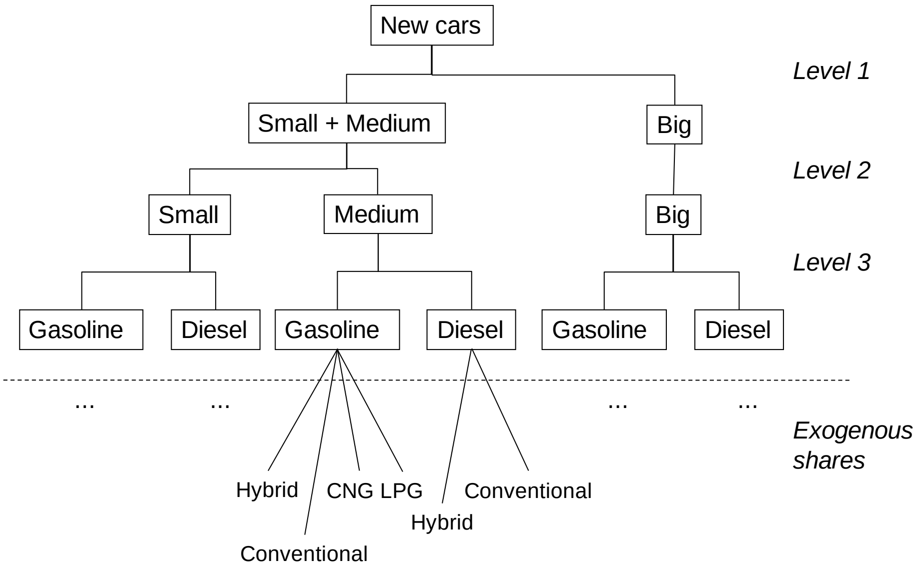
For the technology choice for new vehicles, we consider the choice between three car sizes (small, medium and big)[3] and between different technologies (diesel, gasoline,

[3] The car sizes are defined as follows: 0-1400 cc = small, 1401-2000cc = medium, >2000cc = big.

hybrid diesel, hybrid gasoline, LPG and CNG). The EURO type of the cars is assumed to be determined by the year in which it is bought. The car choice is modelled by means of a nested logit model[4] where the car sale probabilities depend on the monetary variable cost of travel, the monetary income, the annual fixed resources cost and the annual fixed tax.

The decision structure for determining the share of the different car types in car sales is presented in Figure 6. Simultaneously with the choice of the car type, the model also determines the annual mileage of the new cars. In Figure 6 Level 1 describes the choice between small and medium cars on the one hand and big cars on the other hand. Conditional on this choice, the category of small and medium cars is split into small cars and medium cars (Level 2). Finally, given the decision on the car size, the choice between diesel and gasoline cars is determined at Level 3. Finally, the number of hybrid and conventional diesel cars is determined by applying exogenous shares of these two subtypes in total diesel car sales. Similarly, total gasoline car sales are split into conventional and hybrid gasoline cars, CNG cars and LPG cars by applying exogenous shares for these four subtypes.

Figure 6: Decision structure for car purchases



b. Data sources & calibration

In order to construct a reference equilibrium on which to calibrate the model, we collected data on car sales, annual mileage of new cars, variable and fixed costs and monetary income for the year 2005. Table I gives an overview of the different cost components, monetary income (GDP/capita), annual mileage and shares of the different vehicle types in total car sales.

4 For more information about nested logit models see e.g., Koppelman and Wen (1998), Heiss (2002) and Hensher and Greene (2002).

Table I: The reference equilibrium

		Reference equilibrium		
		Small	**Medium**	**Big**
Fixed taxes (EUR/car/year)(1)	Gasoline	448	645	1364
	Diesel	447	769	1381
Variable taxes (EUR/100vehicle-km)(2)	Gasoline	6.5	8.4	10.7
	Diesel	3.4	4.0	5.2
Fixed monetary costs excl. taxes (EUR/car/year)(3)	Gasoline	1163	1924	4109
	Diesel	1323	1955	3476
Variable monetary costs excl. taxes (EUR/100vehicle-km)(4)	Gasoline	8.3	11.7	17.7
	Diesel	6.9	7.4	9.7
GDP/capita (EUR/person/year)		26085	26085	26085
Annual mileage (km/year)	Gasoline	12393	13747	17432
	Diesel	14808	22731	30588
Sale probabilities(5)	Gasoline	19.97%	8.51%	0.78%
	Diesel	27.33%	39.85%	3.56%

(1) Includes registration tax, traffic tax, radio tax and indirect taxation on purchase, insurance and control.
(2) Includes indirect taxation on maintenance and fuel (plus the fuel excise).
(3) Includes purchase, control and insurance costs net of taxes.
(4) Includes fuel and maintenance costs net of taxes.
(5) Observed shares of the different vehicle types in total car sales in base year.
Sources: BFP, CBFA, DIV, IEA, Statistics Belgium, SPF Economics, SPF Mobility and Transport, VITO.

The data for the reference equilibrium show monetary costs rising with size. The variable costs of diesel cars are lower than those of gasoline cars. The fixed costs of diesel cars are higher than for gasoline cars, except for the biggest cars. In the case of big cars this is because the average size of big gasoline cars is larger than that of big diesel cars. Monetary costs cannot fully explain the observed behaviour. As we will see, some characteristics or hidden taste differences cannot be accounted for by using cost data alone. A constant term is therefore introduced in the calibration to the equation for indirect utility (more detail in the next section).

Calibration of the model requires further information on the value of the income elasticity and the elasticity w.r.t. variable costs of annual mileage. Our income and cost elasticities are based on de Jong (1990). The income and cost elasticities of de Jong (1990) are adjusted to account for differentiation by car size. This permits to obtain reasonable elasticities and greatly improves the results.

Table II: Target elasticity values of conditional annual mileage with respect to monetary income and variable costs

Elasticity w.r.t. monetary income	Small car	0.22
	Medium car	0.23
	Big car	0.39
Elasticity w.r.t. monetary variable costs	Small car	-0.14
	Medium car	-0.22
	Big car	-0.45

Given these target elasticities and information on the cost for the base year, the parameters of the indirect utility function can be easily obtained. These parameters correspond to the monetary income elasticity of annual mileage and the elasticity of annual mileage with respect to monetary cost divided by variable monetary cost per km.

c. Output of the car stock module

For each year of the simulation, the vehicle stock module provides the composition of new vehicle sales and calculates average cost data.

As described above, new vehicle sales are calculated each year by comparing the total desired vehicle stock (defined as total vehicle km divided by average annual mileage of the previous year) to the remaining vehicle stock of the previous year after scrappage.

Sales of new cars are then divided among gasoline and diesel cars of different sizes according to the above demand system. A final step calculates the share of LPG, CNG and hybrid gasoline and diesel cars using exogenously defined shares.

For all road vehicle types the vehicle stock module provides outputs on three classes of monetary costs which serve as an input of the Modal and Time Choice module of the next year. It concerns weighted averages, where the weights are the shares of each fuel, size and Euro category in total mileage driven.

The cost categories are:

- Taxes paid per vehicle-km (including all taxes: indirect taxes, excises and fixed taxes)
- Fuel costs per vehicle-km (fuel expenditure including excises and taxes)
- Total monetary costs per vehicle-km (all monetary costs – fixed and variable – including taxes)

In addition, the vehicle stock module determines the annual mileage of the newly bought cars. This is combined with the annual mileage of the older cars, to determine the average annual car mileage. This is used in the next period to determine the total desired car stock (by dividing the number of car vehicle-km by the average annual car mileage).

d. Links of the car stock module with the other PLANET modules

Table III and Table IV summarise the links between the car stock module and the other PLANET modules.

Table III: Input in the car stock module of year *t* from the other PLANET modules

	Input from	Year
Total vehicle km of cars, LDV and HDV	Modal and time choice	*t*
Generalised income per capita	Macro	*t*
Taxes on the various car types	Policy	*t*
Average annual mileage of cars	Vehicle stock	*t-1*

Table IV: Output of the car stock module of year *t* to the other PLANET modules

	Output to	Year
Average emission factors per road transport mode	Welfare	*t+1*
Average monetary costs, fuel costs and taxes per road mode	Modal and time choice	*t+1*

3.3. Assignment

The NODUS model is a detailed network model with an interaction between freight and passenger transport. The network model may be fed by the changes in the origin-destination matrices determined in the trip distribution module of PLANET. PLANET also provides information on the long-term evolution of some transport cost components, such as labour, energy prices, taxes, etc. In the other direction, NODUS can simulate the impact of new infrastructure on the average distance between origin and destination zones, which will affect the transport costs between these zones and the modal and time choice of transport between the zones.

3.3.1. Virtual networks and NODUS.

A simple geographical network does not provide an adequate basis for detailed analyses of transport operations, as the same infrastructure can often be used in different ways. Thus, there is a need for a better modelling of the functions assumed by nodes, i.e. terminals and transhipment platforms, because the costs of the operations performed at these nodes are important in the total cost of transport. Indeed, a geographical multimodal transport network is not only made of links like roads, railways or waterways, on which vehicles move but also of connecting infrastructures at the nodes such as terminals or logistics platforms.

To analyse transport operations over the network, costs or weights must be attached to the links over which the goods are transported as well as to the connecting points where the goods are handled. However, most of these transport or handling infrastructures can be used in different ways and at different costs. For example, boats of different sizes and operating costs can use the same waterway; at a terminal a truck's load can be transhipped on a train, bundled with some others on a boat or simply unloaded as it reaches its final destination. Normally, the costs of these alternative operations are different. In order to model this, one of the solutions is to represent each kind of operation in a node as a specific link of a “virtual network”, for which a relevant cost is then computed. The basic idea was initially proposed by Harker (1987) and Crainic *et al.* (1990). The concept of “supernetworks” of Sheffi (1985), who proposed “transfer” links between modal networks, also provides a similar framework. The concept was systematised and implemented in a software package (NODUS) by Jourquin (1995) and Jourquin and Beuthe (1996), permitting to apply the methodology to extensive multimodal networks.

The network model used for LIMOBEL is implemented in the NODUS software, which was initially oriented towards multi-modal freight transport modelling. Therefore, the methodological approach had to be extended to both freight and passenger traffic. Beside the fact that such a generalisation requires extensive data collection and generation in order to obtain comprehensive origin-destination matrices for commodities and passenger trips, special attention must be paid to two additional topics that are explained in Section 3.3.2.

Once these two issues addressed, the network model will be used to set-up a reference scenario on top of which a series of scenarios will be build, making the link with the other two models.

3.3.2. Improvements for the LIMOBEL project

In the framework of the LIMOBEL project, two aspects of the “virtual network” methodology were improved. First, the concept of lines and services (frequencies) was taken into account. Indeed, trains, for instance, cannot be dispatched using “free” flows, but have to follow “lines”, which may be very different from the shortest or fastest route between an origin and a destination. Moreover, trains circulate at a given frequency. Both concepts are however completely ignored in the original definition of virtual networks, because the different virtual links only take the physical characteristics of the real network into account. The definition of the virtual network was therefore modified in order to correctly model lines and services. As a complete description of this improved methodology goes beyond the scope of this report, the interested reader can find more information in Jourquin et al. (2009). During an assignment, the flows that are transported by “line” modes are now forced to follow the pre-defined lines, while the other modes still can circulate freely. In other words, the new definition of the virtual networks allows to mix “free” and “line” flows inside a single (virtual) network which is an important improvement of the initial methodology.

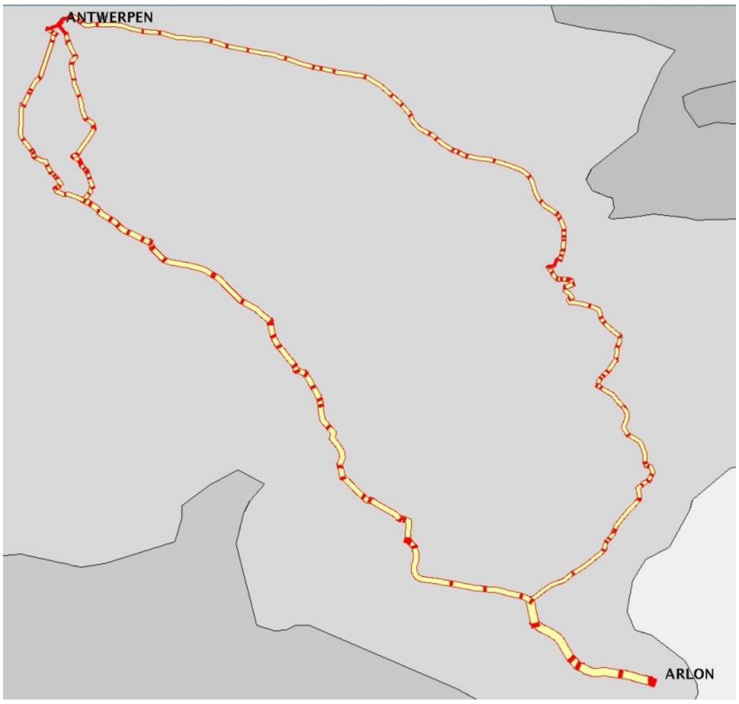
Secondly, the LIMOBEL project mixes passenger and freight flows. So the assignment methods implemented in NODUS were also improved. Indeed, it was not possible to assign both types of transport during the same assignment. There is now a possibility to easily assign in a single step freight and passenger matrices.

It appears (Jourquin and Limbourg, 2006), that equilibrium assignment procedures, which take congestion effects into account, are unable to capture modal and route behaviours when they are applied to larger scale networks such as interregional networks. This is essentially due to the fact that equilibrium models are only efficient at a local level where congestion (or at least heavy flow) is observed. As origin-destination matrices for long distance transport are often available on a yearly basis, it is difficult to estimate what happens during the peak hours. Even more problematic is the fact that long distance transport last several hours and it is not possible, with static models, to know where a vehicle is located at any given moment.

Last but not least, the demand at European level is often available only at the NUTS2 level. At this level of aggregation, it is not realistic to assume that only one route between each O-D pair is used. Therefore a multi-flow algorithm that ensures that the computed set of paths both contains different itineraries and uses different transportation modes is required (Jourquin, 2006). This method spreads the flow over the different paths according to their relative weights in the set of alternative routes.

NODUS and PLANET are complementary tools. The first is a detailed network model that uses as main inputs a digitized network, transport costs and transport demand embedded in origin–destination matrices. The macro-economic data provided as output by PLANET can be used as input to modify the origin-destination matrices and the parameters of the cost functions. The output of NODUS, i.e., a set of data that can be retrieved from an assignment of the demand onto the network (tons, tonne-km, vehicles, average distances, average speed,…) are useful as input for the PLANET model. In other words, both models interact.

Figure 7: Example of a multi-flow assignment for one O-D on the road between Arlon and Antwerp



3.3.3. Description of the network

For this project, a reasonably detailed representation of the networks for the different transportation modes (road, railroads and inland waterways) is needed. Therefore, the railroads and roads networks were taken from the Digital Chart of the World.

The Digital Chart of the World (DCW) is an Environmental Systems Research Institute, Inc. (ESRI) product originally developed for the US Defense Mapping Agency (DMA) using DMA data. The DMA data sources are aeronautical charts, which emphasise landmarks important from flying altitudes. ESRI, in compiling the DCW, also eliminated some details and made some assumptions for handling tiny polygons and edge matching.

Anyway, for the European networks, the proposed data can be used for our needs, after some manipulations in order to obtain a coverage corresponding to the European countries.

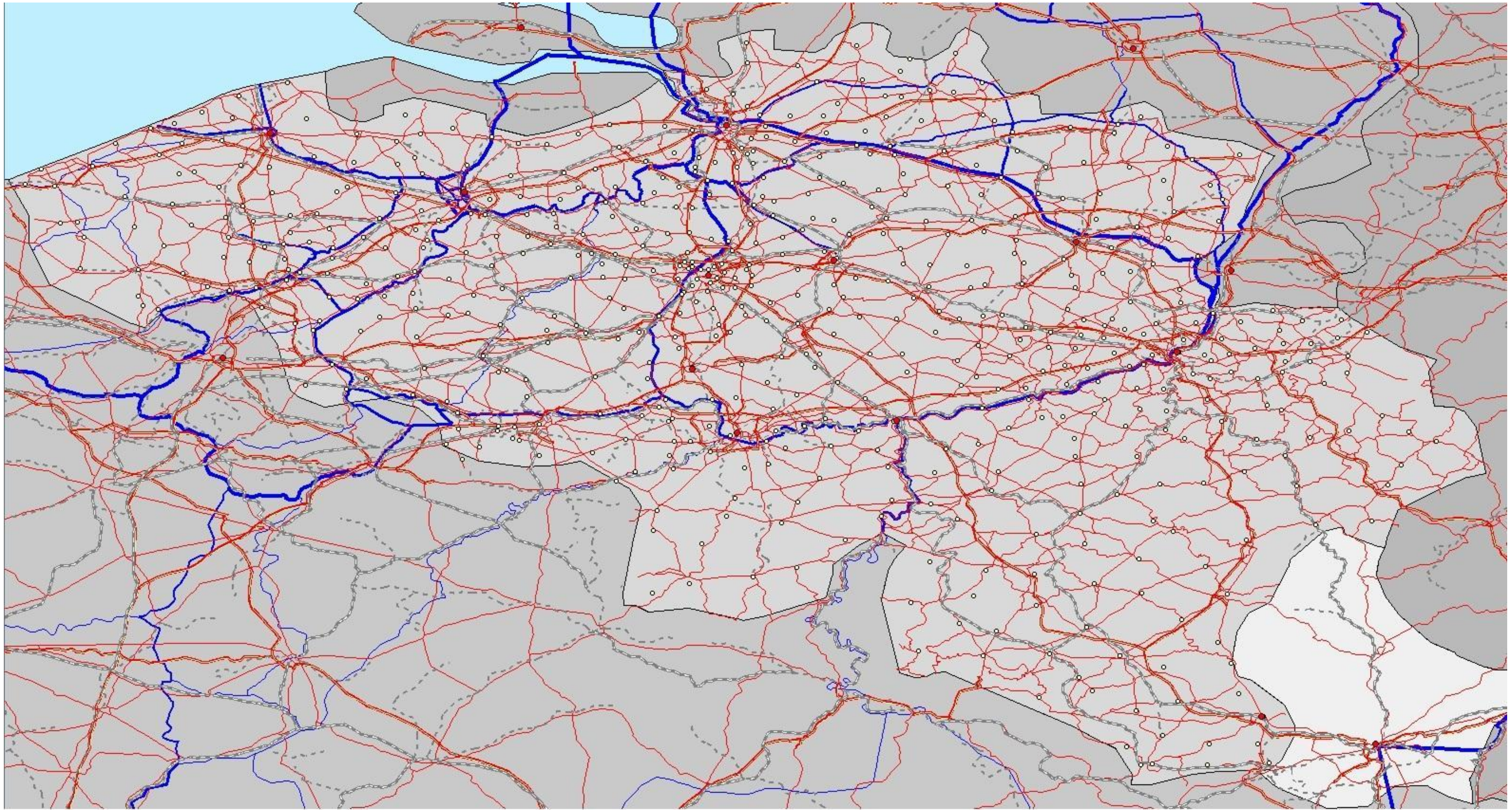
The inland waterways network does not exist in the DCW. There is a “drainage” layer, but it is not detailed, and does not correspond to the waterways on which barges can be used. Therefore, the corresponding network was digitalised by the Group of Transport & Mobility of FUCaM.

Moreover, the Belgian road network is more detailed compared to those of the other countries.

The borders of the NUTS2 regions were freely obtained from GISCO (although this data is not public). This data set was used to compute the centroid of each region that will then be used as starting and/or arriving node for the commodities, using the algorithm proposed by Bourke (1988).

All these separate layers (roads, railways, inland waterways and centroids) were then connected together, using “connectors” from each centroid to each modal layer located not further than a given distance. Even if not completely up-to-date, this complete pan-European network has certainly enough details to make our simulations realistic. A map of the network is given in Figure 8. Annex 6 provides the maps for the three modes separately.

Figure 8: Belgian network (3 modes)



3.3.4. Data sources and calibration

a. Freight transport

For the freight transport matrices, the original data come from the TRANS-TOOLS project. The data describe the transportation chain from each origin to each destination. So, the chains are composed of an origin, a destination, zero to two transhipment zones, a mode for each stage, a commodity group and a quantity. In other words, the records are such as (the letters are origins or destinations or transhipment zones):

A => maritime transport => B => train => C | 4 | 1755

or

E => truck => F => train => G => truck => H | 2 | 2146

The first operation is to convert the NUTS codes of the origins, destinations and transhipment zones into NODUS codes.

Moreover, these chains of transportation must be split up in order to have origin-destination pairs like:

A => B maritime transport | 4 | 1755
B => C train | 4 | 1755
E => F truck | 2 | 2146
F => G train | 2 | 2146
G => H truck | 2 | 2146

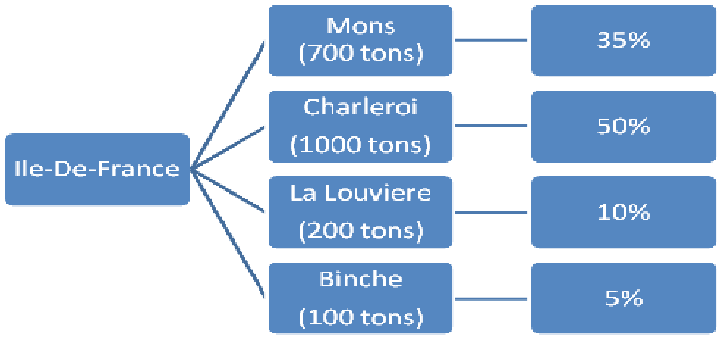
For the LIMOBEL project, the maritime segments were deleted and all the NST/R groups of commodities were merged. Moreover, as the LIMOBEL project only concerns Belgium, a NODUS script was written in order to keep only the flows that are located in Belgium, or relevant for import/export and transit.

The TRANS-TOOLS data are available at the NUTS2 level. While this granularity can be considered as satisfactory for the European countries beside Belgium, we have, in the framework of LIMOBEL, a need for NUTS5 (municipalities) data for our country.

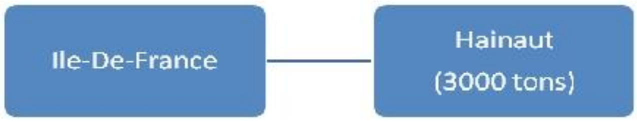
To solve this, we have calculated an attractivity-index for each NUTS5 area in each Belgian NUTS2 region. It could however be done only on the basis of 1995 data available at the Group of Transport & Mobility of FUCaM. This can be illustrated by means of an example:

Figure 9 : Construction of O-D data at NUTS5 level – example

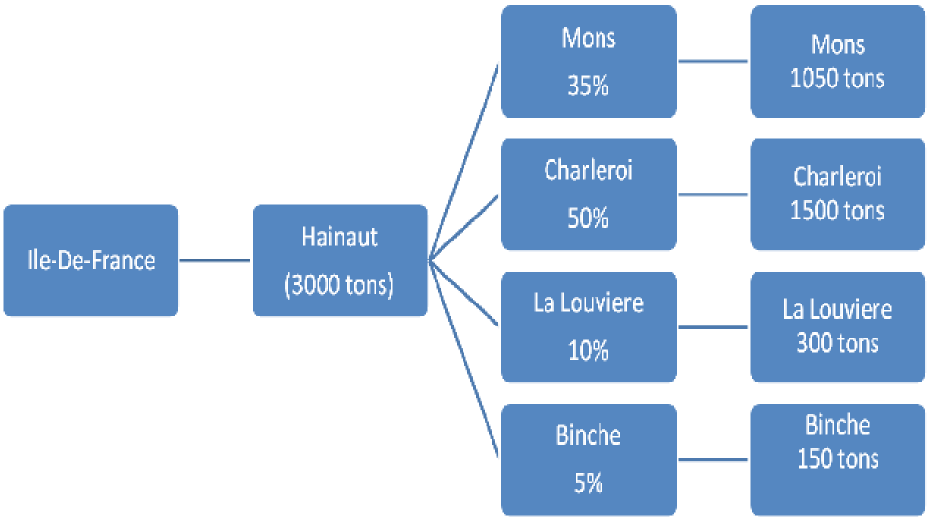
Part 1: 1995



Part 2: 2005



Part 3: 2005



In our example, if we assume that there are only four cities (NUTS5) receiving quantities in Hainaut from Ile-De-France (NUTS2), we start from the share of each city in 1995 in all tonnes arriving in Hainaut (Part 1 in Figure 9).

We obtain four NUTS2 to NUTS5 pairs instead of one NUTS2 to NUTS2 pair (Part 3 in Figure 9).

This method is applied to the complete matrix. The resulting matrices have a NUTS2 to NUTS2 granularity for the transit flows, NUTS5 to NUTS2 for export, NUTS2 to NUTS5 for import and NUTS5 to NUTS5 for the Belgian national trips.

b. Passenger transport

For passenger transport, the data are based on figures made available by Statistics Belgium. These matrices however concern only Belgian national flows. Each row of the data gives a quantity, an origin, a destination, a time (a.m. peak or p.m. peak or off-peak), a purpose (work or school) and a transport mode (a mode name and a mode code). To make the data usable in NODUS, the NODUS node numbers are set for the origins and destinations; the pairs are grouped by origin, destination and mode (neither time or purpose were taken into account). Moreover, only inter-urban trips were taken into account in the model, in order to remain consistent with the freight O-D matrices. We obtained matrices for rail, busses, cars and motorbikes.

After a matrix correction (see Section 3.3.5.a), the matrices of busses, cars and motorbikes were merged into one road matrix.

3.3.5. Difficulties and solutions

a. Matrix correction

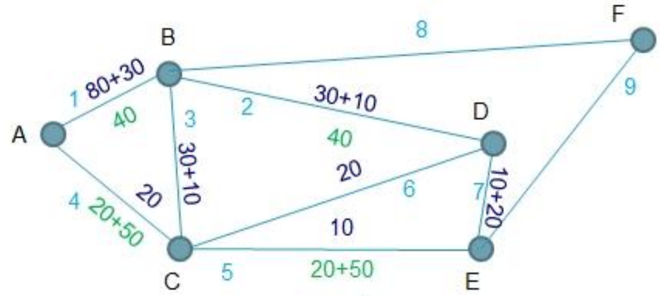
The set of available matrices is however not complete. Indeed, for passenger transport, only home-work and home-school trips are available, ignoring all the trips that concern other travel purposes. For freight transport, the flows related to empty trucks are also missing. In order to take into account these missing flows, an innovative method of matrix correction, based on counts along some links of the network, was developed and applied.

Generating or modifying an origin-destination matrix by means of counts along the infrastructure is a well known problem, although not easy to solve. The method that was developed, is based on a rather unique feature of NODUS, which has the ability to save not only the results of the assignment but also the details of all the routes that were computed between all O-D pairs. These details are available even when equilibrium or multi-flow assignments are performed. The principle of the method is rather simple: the original O-D matrix is assigned to the network and then the assigned quantities on each link for which a count is available, are compared with these counts. Then, each O-D pair between which at least one route passed along a link with counts, has its demand modified according to the difference between the assigned and counted flows. This procedure is repeated in a loop until an acceptable global error threshold for the whole assignment (e.g., 2%) is reached.

An illustration of this method is given in Figure 10.

Figure 10: Illustration of the matrix correction method

O-D	Qty
AB	80
AD	50
BC	30
BE	20
DA	60
EA	50



Link	Assigned Qty	Observed Qty	% of difference
1	110	130	18.2%
-1	40	50	25%
2	40	45	12.5%
-2	40	60	50%
3	40	55	37.5%
4	20	/	/
-4	70	84	21.4%
5	10	15	50%
-5	70	/	/
6	20	25	25%
7	30	40	33.3%

O-D	Qty
AB	(80 * 1.182) = 95
AD	[(50*60%)*((1.182+1.125)/2)] + [50*40%)*(1.25)] = 34,605 + 25 = 59,605
BC	(30*1.375) = 41,25
BE	(20*50%)*((1.125+1.333)/2] + [(20*50%)*((1.375+1.5)/2)] = 12.29 + 14.375 = 26.665
DA	[(60*66.67%)*((1.5+1.25)/2)] + (60*33.33%)*((1.333+1.214)/2)] = 55 + 25.47 = 80.47
EA	(50*1.214)=60.7

The original O-D matrix is assigned on the network. The assigned and observed quantities are compared to set a percentage of difference for each link. According to these percentages, each O-D pair can be corrected. For example, for the pair A-B, the original quantity was 80, corrected by the difference rate, it gives 95. For the A-D pair, there are two paths, one from A to B to D (30=>60% of 50), and another from A to C to D (20=>40% of 50). Each path takes two links, the correction is thus done with the average difference rate of both links. When the observation is not available for a link, no correction rate is applied for that link.

After the correction, we obtain another matrix on which the assignment runs, then the difference rates are computed to allow the correction of the matrix till the chosen threshold is reached.

b. Quality of the matrices

One of the biggest difficulties that we encountered was the quality of the data from TRANS-TOOLS for freight transport. Indeed, for the first version of data, the tonne-km for trucks were overestimated in comparison with the figures of the "Pocketbook". We received new data for which this problem was resolved.

Moreover, for the transport by barges, we observed a bad dispersion of the TRANS-TOOLS flows, probably because of bad quantities for the origin-destination pairs composing the matrix. With the new version of data, the problem persisted; it was solved thanks to the matrix correction method.

This problem of the matrices' quality could seem irrelevant, but all the work done on the first version of data had to be done again on the new version leading to a substantial time loss in the project.

c. Lines and services

As explained, a method to take into account the lines and services, a characteristic of the transport by train, was developed. The method was successfully tested on the Belgian network, but was not implemented at the European level in the context of LIMOBEL, as the necessary input of data is very important (several man/months) and the details of the lines and services for all the countries that are included in the model were not easily available.

3.3.6. Reference matrices

After these correction, we obtained reference matrices for freight and for passenger transport for each mode. These matrices were assigned and give us reference flows. The different matrices of each type of transport were merged to obtain one matrix for freight transport and one matrix for passenger transport, allowing multimodal assignments in NODUS.

The cost functions[5] had to be calibrated to obtain similar tonne-km or passenger-km for the multimodal assignments as for the "monomodal" assignments. For example, if we look at the case of freight transport, each assignment provides tonne-km:

"Monomodal" assignments		Multimodal assignment	
Matrix	**Output**	**Matrix**	**Output**
Freight road	→ Tkm_rd_mono	Freight	→ Tkm_rd_multi
Freight rail	→ Tkm_rr_mono		→ Tkm_rr_multi
Freight IWW	→ Tkm_ww_mono		→Tkm_ww_multi

[5] The cost functions are based solely on the distance and speed.

After the calibration, we have to find something like :

Tkm_rd_mono = Tkm_rd_multi
Tkm_rr_mono = Tkm_rr_multi
Tkm_ww_mono = Tkm_ww_multi

The same process is used for passenger transport (but there are only two modes : road and rail).

The calibrated reference scenario is summarised in the following tables :

Table V: Freight transport: calibrated reference scenario in NODUS

	Data		Multimodal (calibrated)	
	Tonnes	**Tonne-km**	**Tonnes**	**Tonne-km**
Road	87%	82%	81%	83%
Rail	5%	11%	9%	11%
IWW	7%	7%	10%	6%

Table VI: Passenger transport: calibrated reference scenario in NODUS

	Data		Multimodal (calibrated)	
	Passengers	**Passenger-km**	**Passengers**	**Passenger-km**
Road	91%	88%	88%	88%
Rail	9%	12%	12%	12%

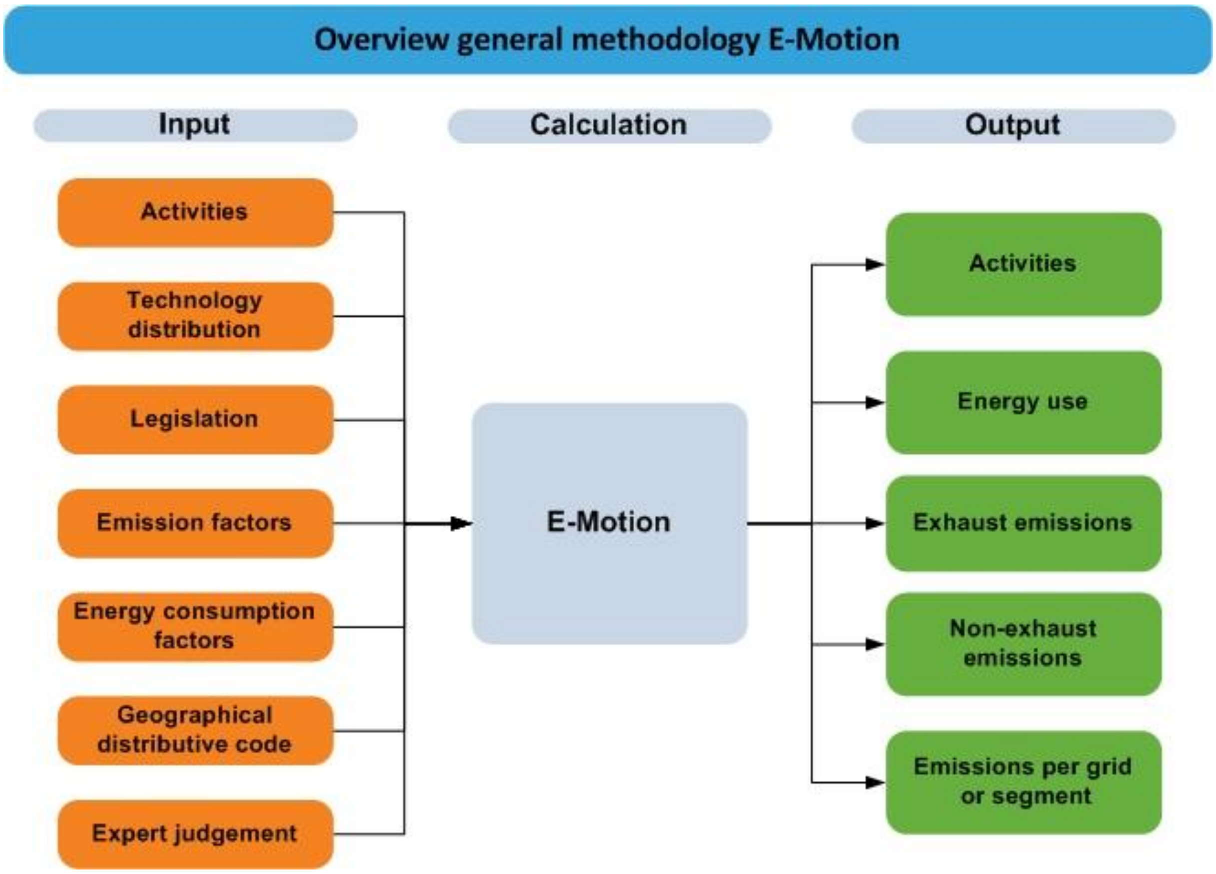
Although the distributions for the tonnes/passengers could be better, the results for the tonne-km/passenger-km are very good.

3.4. Environmental impacts and external costs

3.4.1. Environmental impacts

In this section we report about E-motion, the energy and emission model for transport developed by VITO. E-motion is the acronym for 'Energy- and emission MOdel for Transport with geographical distributION'. The environmental impact model calculates and geographically distributes energy consumption and emissions from road transport, rail traffic, inland navigation, maritime transport and off-road transport for Flanders, Wallonia and the Brussels region. Not only inventory studies, but also scenarios can be calculated. Figure 11 gives an overview of the general methodology of all modules in E-motion. Furthermore, future technologies are presented in all modules.

Figure 11: Overview of the general methodology of the different modules in E-motion



E-motion uses a bottom-up approach to quantify the environmental impact of different transport modes. Detailed statistical activity data - mobility and fleet data - are transformed into the right format for the emission calculations. At this moment activities from the year 1990 up to 2008 are present in the model for all transport modes. Close watch on the evolution in technologies and mobility makes it possible to set up different scenarios for future years. Different scenario evaluations up to 2030 (De Vlieger et al., 2009; Pelkmans et al., 2011) and vision exercises up to 2060 (Michiels et al., 2011) have already been performed.

The basic formula for calculating energy consumption and emissions from different transport modes is:

$$Emission_i = \sum_{t=0}^{n} activity_{t,i} \times emission\ factor_t$$

$$Energy\ consumption_i = \sum_{t=0}^{n} activity_{t,i} \times energy\ consumption\ factor_t$$

With *i = year*

t = technology

Emission and energy consumption factors are technology specific, e.g. fuel type, age, after treatment, retrofit. The introduction level of new technologies, as well as the energy consumption level of new technologies, is strongly dependent on present and future legislation. The model calculates exhaust emissions and also the non-exhaust particulate matter and metal emissions.

All modules in E-motion not only aim at calculating total emission evaluations, but also calculate geographically distributed emissions. This is a necessary step to quantify the impact of traffic flows on air quality. VITO also made a tool for each transport mode that easily computes emission results for a specific part within a region, e.g. city, province, own definition of a grid, ... without having to define specific activity data for this specific region.

In the following we describe the updated approach and data sources for all transport mode successively. To come up with weighted emission factors for the PLANET and NODUS model, we first define a scenario. Secondly, we run E-motion which results in disaggregated emissions and activities. Finally, we combine these results to the agreed aggregated level. In addition, we give an update of the emissions during production and transport of energy carriers. For off-road transport, we refer to the OFFREM report (Schrooten et al., 2009), as the output of this module was of no interest within LIMOBEL.

a. Road traffic

The heart of the road module within E-motion is MIMOSA. Emission and fuel consumption rates for each trip are expressed as functions of average speed. Within LIMOBEL and the MIMOSA4 study (Vankerkom et al., 2009), VITO refined, extended and revalidated MIMOSA. The latest version of MIMOSA relies on the COPERT 4 energy consumption functions for the conventional fuels (diesel, petrol and LPG) (EMEP/CORINAIR, 2007). For alternatives VITO integrates its own expertise (measurements and literature) and international network. Additionally for passenger cars, the results of the CO_2 monitoring and the effects of the CO_2 legislation are integrated in the module. Within the module eight vehicle categories can be distinguished with further sub-categories depending on the technology, the age of the vehicle and its cylinder capacity or tonnage.

The handling of rough data on road vehicles from different data sources (FPS Transport and Mobility, DIV, De Lijn, MIVB, TEC and Febiac) is further computerized within Vlool (fleet inventory) module. The outcome of Vlool is a region specific vehicle stock from 1993 up to the last available historical year with corresponding mileages per vehicle type, class, technology and age. Besides the age of a vehicle, also the Euro-norm is an important parameter that influences the fuel consumption and polluting behaviour of vehicles. We used the implementation date of European emission directives for new vehicles to link each vehicle to a Euro-norm class. Hereby, we expect that new technologies are introduced some months before directives come into force.

Annex 1 gives a detailed description of the road module.

We computed the energy consumption and emission factors on the required level for PLANET and NODUS on the basis of two BIOSES scenarios without biofuel blends, the baseline scenario (BAS0) and the energy savings scenario (ES0) (Pelkmans et al., 2011). The biofuels are not yet integrated in the fleet emission factors to make it possible to consider biofuels separately in the PLANET model. We provided FPB with the effect of the biofuel blends on the exhaust emissions. Concerning exhaust emissions biofuels are considered to be CO_2 neutral and the effect of other pollutants is taken from EMEP/CORINAIR (2007). The BAS0 and ES0 scenarios for Belgium are a derivative of, respectively, the ‘MIRA Referentie’ and ‘MIRA Europa’ scenario for Flanders (De Vlieger et al., 2009). Besides the different geographical scope, updated vehicle stock data and mileages are used for the three Belgian regions up to 2008, the introduction of euro VI heavy duty vehicles is already taken into account in the baseline scenario, targets of the CO_2 legislation are implemented in the baseline scenario instead of voluntary targets of the ACEA agreement, no biofuel blends are introduced and the energy consumption and emission factors for alternatives are based on own expertise instead of COPERT IV (EMEP/CORINAIR, 2007).

Validation

The outcome of E-Motion Road has to be validated. To this end, the energy consumption generated by the model are compared to VITO’s previous model SUSATRANS, estimating the energy consumption and emissions for road transport.

The results of this comparison show that some differences exist between the two models. Further analyses indicate that these differences can be attributed to methodological adjustments on the one hand (Vankerkom et al., 2009), and to changes observed in the input data. The former aspect covers two items. Firstly, the refinement of the generic speeds used in the model causes almost 50% of the difference between the two compared models. Secondly, an update of the emission functions applied in both models (MIMOSA III is used in SUSATRANS while MIMOSA IV is used in E-Motion Road) can be held responsible for part of the remaining share of the difference, which mainly impacts the energy consumption of heavy duty vehicles. The latter aspect includes changes in the number of kilometres reported by FOD, and also principally affects heavy duty.

Results and analyses

Exhaust emission factors

Table VII shows exhaust fleet emission factors for road transport for the two defined scenarios, on the level of the vehicle category.

Table VII: Fleet exhaust emission factors for road transport (g/km)

Vehicle category	Pollutant	Historic 2007	Baseline 2010	Baseline 2020	Baseline 2030	Policy 2010	Policy 2020	Policy 2030
MOTO	CO_2	86	83	79	76	83	76	74
	NO_x	0.186	0.222	0.237	0.252	0.222	0.235	0.251
	$PM_{2.5}$	0.070	0.056	0.033	0.022	0.056	0.034	0.022
CAR	CO_2	161	157	133	114	157	113	78
	NO_x	0.639	0.543	0.277	0.137	0.539	0.272	0.114
	$PM_{2.5}$	0.029	0.022	0.007	0.004	0.022	0.007	0.003
LDV	CO_2	225	226	204	181	226	189	154
	NO_x	1.058	0.963	0.499	0.268	0.963	0.500	0.242
	$PM_{2.5}$	0.078	0.062	0.013	0.003	0.062	0.013	0.002
HDF	CO_2	689	711	663	659	711	629	622
	NO_x	6.737	5.236	0.990	0.546	5.237	0.994	0.546
	$PM_{2.5}$	0.139	0.080	0.016	0.012	0.08	0.017	0.012
HDP	CO_2	804	691	637	608	691	628	583
	NO_x	8.185	5.115	1.441	0.489	5.109	1.464	0.480
	$PM_{2.5}$	0.207	0.096	0.022	0.013	0.096	0.022	0.012

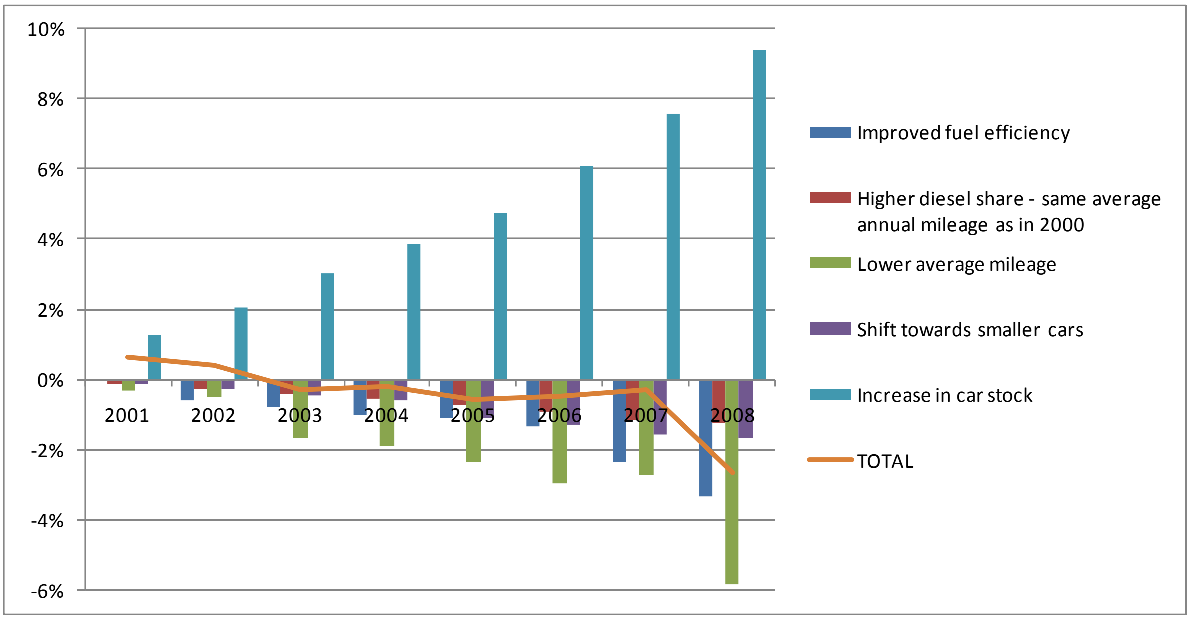
LDV: light duty vehicle; HDF: heavy duty freight vehicle; HDP: heavy duty passenger vehicle

In general the fleet emission factors (Table VII) decrease for all vehicle types and all pollutants in the period 2007-2030. This is more pronounced in the policy scenario than the baseline scenario, as more stringent emission legislation is assumed up to euro 6 (cars & light duty vehicles) and euro VI (heavy duty vehicles) and more policy measures are taken up. However, less improvement is found for CO_2 as exhaust treatment is not possible here. Lower CO_2 emissions are obtained by more efficient motor fuel technologies (e.g. hybrid vehicles). The policy scenario takes into account a higher penetration of hybrid technologies, the implementation of eco-driving and low-energy tyres and for heavy trucks the introduction of sides skirts. The reduction of CO_2 emissions for passenger cars is more pronounced due to the EU legislation on CO_2 limitation for new cars and a significant penetration of alternative motor fuel and vehicle technologies in the policy scenario. The low CO_2 emission factors for cars under the policy scenario in 2030 are due to the considerable rise in electric traction. Of the total car fleet in 2030 about 20% will be plug-in hybrid vehicles and 4% electric battery vehicles. More information on the baseline and policy scenario to come up with fleet emission factors for the PLANET model can be found in Annex 1.

The historical evolution of CO_2 emissions by the car fleet in Belgium

Figure 12 shows the CO_2 emissions caused by passenger car fleet in Belgium. The blue line represents the percentage change in CO_2 emissions in the period 2001-2008 with respect to the emission levels in 2000. By 2008 these emissions have fallen by 2.6% compared to 2000; the largest reduction taking place between 2007 and 2008. This evolution is the result of multiple aspects, in particular changes in the total number of cars, changes in the share of different car sizes and fuel types, changes in the annual mileage of cars and changes in the fuel efficiency.

Figure 12: Decomposing the evolution of CO_2 emissions by the Belgian car fleet between 2000 and 2008



To this end, Figure 12 displays for each year an estimation of the contribution of the different elements to the evolution of emissions with respect to 2000. Each of the bars gives the additional impact as the different determinants of the CO_2 emissions are changed one by one from the 2000 level to the level of the year that is considered.

- The first bar gives the impact of the increase in fuel efficiency compared to 2000, keeping all other determinants of the emissions constant at their 2000 level. As can be expected, this leads to a reduction in CO_2 emissions (-3.3% for 2008).
- The second bar returns the additional reduction due to the higher share of diesel cars, keeping the average annual mileage constant at the level of 2000 (-1.2% in 2008).
- Next, the third bar accounts for the decline in the average annual mileage between 2000 and 2008, leading to lower CO_2 emissions (-6% in 2008). This reduction in the average annual mileage between 2000 and 2008 is

observed both for diesel and gasoline cars. It has been somewhat larger for diesel than for gasoline cars, and differs according to vehicle size.

- Between 2000 and 2008 the average size of the cars has also decreased, resulting in a reduction of CO_2 emissions, as represented by the fourth bar (-1.7% in 2008).
- Finally, the total number of cars has risen, causing the CO_2 emissions to increase as well (+9.4% in 2008).

Aggregating the impact of all these changes, results in the total effect as represented by the orange line in Figure 12. The dieselization of the car fleet and the change in average annual mileage together give rise to a fall in the CO_2 emissions by 7.1% w.r.t. 2000, which is reinforced by the rise in fuel efficiency and the higher share of smaller cars, and counteracted by the increase in the total number of cars.

Differences in annual mileages of cars between regions

Figure 13 and Table VIII show the average annual mileage driven by cars in 2008 compared to the corresponding numbers in 2000. A distinction is made according to fuel type and region. In particular for petrol cars, these numbers diverge. The smallest decrease in the annual number of kilometres driven by petrol cars is observed in the Walloon region. The numbers for the Brussels region have to be interpreted with care, as they reflect the number of kilometres driven in Brussels divided by the number of cars registered in Brussels. However, the number of kilometres travelled by car in Brussels are not principally travelled by cars registered in Brussels. Moreover, a large share of the cars registered in Brussels consists of company cars, which usually travel frequently outside the Brussels Capital Region as well. Consequently, the average annual mileage for the Brussels region is underestimated.

Figure 13: Decrease in the average annual mileage for cars for 2008 compared to 2000

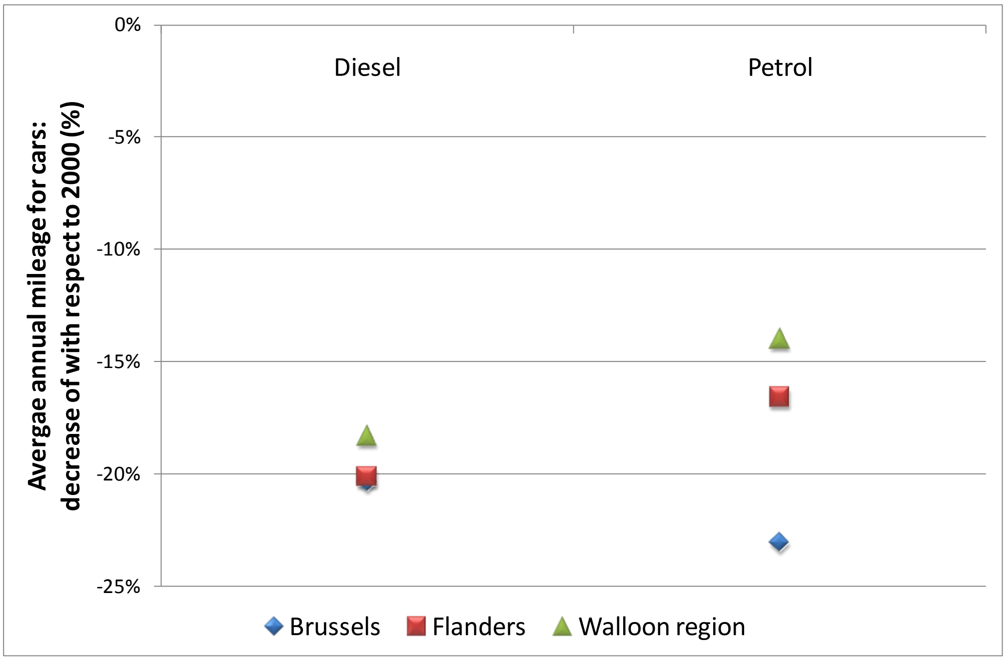


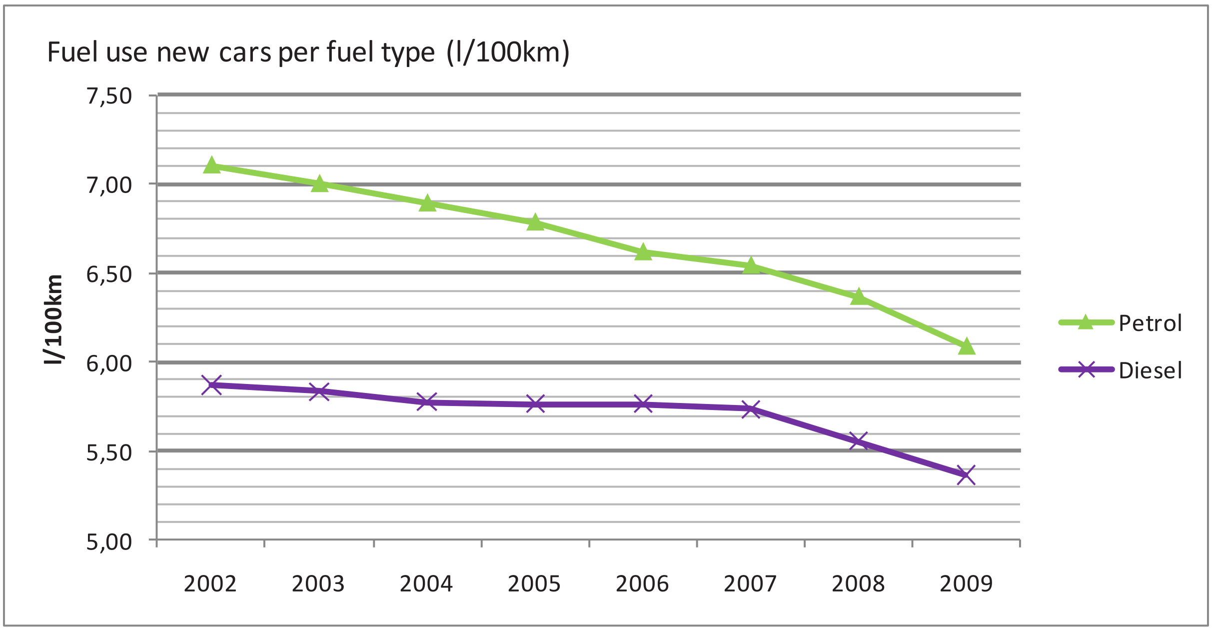
Table VIII : Average annual mileage of cars in 2000 and 2008 (km)

Year	Fuel	Brussels	Flanders	Walloon region
2000	petrol	3 677	9 256	11 953
	diesel	10 846	23 148	30 946
2008	petrol	2 829	7 719	10 277
	diesel	8 636	18 485	25 268

Drop in fuel consumption and CO_2 emissions of new passenger cars in Belgium

Figure 14 shows the evolution of the fuel consumption (CO_2 emissions) of new petrol and diesel fuelled passenger cars in Belgium according to the European type approval test cycle. A decrease can be seen for both diesel and petrol cars.

Figure 14: Evolution of the fuel consumption of new cars in Belgium per fuel type.



Downsizing of the engines (lower cylinder capacity for the same power) during the latest 8 years is responsible for a part of this decrease. The decrease however is more pronounced for petrol cars than for diesel cars. Figure 14 shows only a small reduction in the fuel consumption for diesel cars between 2004 and 2007. This can be explained by the increase in sales figures of diesel cars with large cylinder capacities. The stronger decrease after 2007 can be explained by the increase in sales figures of small diesel cars. This evolution was encouraged by different policy measures: the direct discount for new energy efficient diesel cars and the dependency of the tax deductibility on the CO_2 emissions for company cars since 2007.

Furthermore, there is an increase in sales of green cars. These include hybrid vehicles and low CO_2-emitting petrol and diesel fuelled vehicles (by e.g. improved aerodynamics, start-stop systems, lower rolling resistance).

CO_2 emissions can directly be deduced from petrol and diesel consumption figures. So, CO_2 emissions drop also from 2002 to 2009. In 2009 the average CO_2 emission from new passenger cars in Belgium was 144.3 g/km. The European directive EC/443/2009 enforced an average for the entire EU of 130 gCO_2/km by 2015. The evolution of CO_2 emissions from new cars shows it will possibly not be reached by 2015 in Belgium. But, if CO_2 emissions from new cars continue to follow the evolution of the last three years (2007-2009) (Figure 14), it would be easy to meet the objective for Belgium. At this stage it is however not yet clear whether the recent evolutions are structural or due to the economic crisis.

b. Rail traffic

Next to estimating the energy consumption and emission caused by road transport, E-Motion also includes a module to calculate these indicators for rail transport. The calculation of emission and energy consumption factors for rail transport within E-Motion is implanted on the methodology of Ex-TREMIS on the one hand (Chiffi et al., 2009), and on the methodology forwarded in EMMOSS on the other hand (Vanherle et al., 2007). The methodology will be explained concisely in the next paragraphs. For more details, we refer to Annex 1.

The model starts from yearly activity data concerning the number of train kilometres, disaggregated according to train type (goods vs. passenger), energy source (diesel vs. electricity), service type (IC, IR, L, P, HST or goods), as reported in the statistical annual reports of the Belgian Railway Company (NMBS/SNCB). To estimate the number of train kilometres for the scenarios defined in this project, the data of the last available historical year is combined with Flemish growth rates assumed in MIRA-S (De Vlieger et al., 2009), which are assumed to apply to railway transportation in Belgium as well.

Starting from these data, the model estimates the number of gross tonne-km travelled by both the Belgian Railway Company and non-NMBS/SNCB operators on the Belgian railway network. Next, these numbers are split up according to the traction type (locomotive vs. multiple unit).

The resulting gross tonne-km are used as basis for calculating the corresponding energy consumption by applying the specific energy consumption factors for trains/services in Belgium. Subsequently, a supplement on the energy consumption is added to account for shunting activities. In the following step, the calculated energy consumption is calibrated, based on the total energy consumption per train type and energy source reported by the National Railway Company in their annual statistics.

Further, to enable accurately calculating the emissions of rail transportation in Belgium, the technological evolution of diesel engines is included in the model. Therefore, the energy consumption figures are split up to include the technology class of the diesel engines. The technology classes used in our model are based on the starting date of the type approvals for train engines and the European legislation 2004/26/EC. More information on the exact definition of these technology classes is found in Annex 1. Next to implementing more up-to-date input data, this inclusion of the detailed technology classes is a major improvement of our model with respect to the previous version.

The outcome of these calculations consists of the energy consumption per train type, service type, energy source, technology class and activity (mainline or shunting). These detailed energy consumption figures constitute the basis to calculate exhaust emissions by multiplying them with emission factors reported by IPCC (1997, 2006) for the fuel-related emission factors (CO_2, N_2O and CH_4), in European emission regulation while accounting for the specific Belgian sulphur content for SO_2 (FAPETRO, 2003) and in the European legislation 2004/26/EC, an amendment of 97/68/EC, for the technology-related emission factors (NO_x, PM, CO and HC).

Conversely, non-exhaust emissions are estimated based on the number of train kilometres travelled on the Belgian railway network and the corresponding non-exhaust emission factors reported on by Sleeuwaert et al. (2006).

Finally, both the calculated exhaust and non-exhaust emissions as well as the resulting energy consumption are converted into emission factors. This output of the model is included in the PLANET-model.

Table IX glimpses at the exhaust emission factors for CO_2, NO_x and $PM_{2.5}$ for rail transportation by diesel engines for one historic year (2007) and for the forecast for 2010, 2020 and 2030 in the baseline scenario. The emission factors are split up based on the train type (goods vs. passenger) and their activity type (mainline vs. shunting). For more emission factors, as well as non-exhaust emission factors and energy consumption factors, we refer to Annex 1.

Table IX: Exhaust emission factors for diesel rail transportation
(g/gross tonne-km)

Train type	Pollutant	Historic	Baseline		
		2007	2010	2020	2030
Goods – mainline activities	CO_2	13.2	13.9	12.8	12.8
	NO_x	0.226	0.180	0.178	0.178
	$PM_{2.5}$	0.005	0.004	0.004	0.004
Goods – shunting activities	CO_2	0.737	0.552	0.469	0.468
	NO_x	0.011	0.007	0.006	0.006
	$PM_{2.5}$	0.000	0.000	0.000	0.000
Passenger transport	CO_2	35.5	35.0	32.9	32.9
	NO_x	0.330	0.325	0.115	0.115
	$PM_{2.5}$	0.007	0.006	0.002	0.002

As can be seen in Table IX, the exhaust emission factors for diesel rail transportation decrease, due to efficiency and technological improvements, as assumed in the Rail energy project (UIC, 2006) and imposed by the European legislation 2004/26/EC respectively.

c. Inland navigation

The module for inland navigation within E-Motion is responsible for estimating the emissions and energy consumption of inland navigation. These estimations are the product of emission factors and tonne-km. The methodology is elaborated in detail in Annex 1, and is summarized here.

The module for inland navigation is inspired by the EMS protocols (Ministerie van Verkeer en Waterstaat, 2003a, 2003b). Because very detailed data are only available for the activities on the waterways under the administration of nv De Scheepvaart, the model first calculates emission and energy consumption factors for these waterways. As these waterways are assumed to be representative for all waterways in Belgium, the outcome of the calculation steps for these waterways - taking into account the size of the waterways as defined by the CEMT class of the waterway - is applied to all waterways in Belgium.

In order to calculate the emission and energy consumption factors for the representative waterways, the inland navigation ships are categorized according to the ship type (motor vs. push ship), the ship class (e.g. Kempenaar, Large Rhine ship, small push combination) and tonne class (e.g. < 300 tonne, 301-650 tonne, …, > 2000 tonne), next to a classification according to the load factor (loaded vs. unloaded). Furthermore, a division of the ships with respect to the technology class of the build year of the propulsion engine(s) is included in the model. For this purpose, the EMS protocols (Ministerie van Verkeer en Waterstaat, 2003a, 2003b) distinguish 7 technology classes. The last class, containing the most recent technology CCR-1, is further subdivided within E-Motion for inland navigation, conform the classes defined in EMMOSS (Vanherle et al., 2007).

Starting from these data and the methodology forwarded in the EMS protocols (Ministerie van Verkeer en Waterstaat, 2003a, 2003b), the required power can be calculated, and, based on that, the energy consumptions can be derived. Subsequently, the fuel consumption and emissions linked to these activities can be estimated. The corresponding energy consumption and emission factors per CEMT class for these representative waterways form the basis of the calculations of the energy consumption and emissions caused by inland navigation for all waterways within Belgium.

To this end, historic data concerning the activities on these waterways are gathered and prognoses concerning the future activities are formulated. The historic data consist of the number of tonne-km travelled on the waterways, as reported by the different waterway administrations. For the harbours, the total number of tonne-km for all harbours in Belgium is estimated based on data of the Studiedienst van de Vlaamse Regering, recording the total number of tonne-km for all regions including the harbours. The number of tonne-km for all harbours is dispersed over the different harbours according to their share in the total charged and discharged tonnes in the Belgian harbours. For the prognoses of the tonne-km, the last available statistical data are combined with annual growth rates for Flanders, as recorded in MIRA-S (De Vlieger et al., 2009), assuming the same growth rates for Belgium.

The development of this module for inland navigation has reached its final phase, and only requires validation. The results of the geographic approach per CEMT class are expected in spring of 2011. Consequently, we have chosen to use within LIMOBEL the TEMAT_2005_inland navigation model, developed and validated within SUSATRANS (De Vlieger et al., 2005). This model also applies a detailed classification of the ship types in technology classes, conform the inland navigation module within E-Motion. The TEMAT-model defines less ship types and tonne classes, and does not disaggregate geographically per waterway.

As is the case in E-Motion, the TEMAT-model accounts for the total energy consumption of ships, which includes the following three energy systems:

- The energy consumption of the propulsion engine(s), employed to drive the ship;
- The energy consumption of the screw propeller engines, responsible for manoeuvring;
- The energy consumption of auxiliary engine(s), used for heating and electricity supply on board.

Additionally, the TEMAT model takes into account the load factor of ships and the share of unloaded ships. The fuel consumption within TEMAT is calibrated for the year 2002, based on a survey concerning the fuel consumption executed on inland navigation ships on Flemish waterways (De Vlieger et al., 2004).

The N_2O emission factor within TEMAT appeared to be rather high. Therefore, we decided to apply IPCC emission factors within the inland navigation module within E-Motion (IPCC, 1997).

Table X shows the evolution of the fleet emission factors for inland navigation in Belgium for the pollutants CO_2, CH_4, N_2O, NO_x and PM_{10}. For the other pollutants we refer to Annex 1. The fleet emission factors reflect the emission factors weighted over the different ship types and technology classes.

Table X: Fleet emission factors for inland navigation in Belgium
(g/1000 tonne-km)

Pollutant	Baseline			
	2007	**2010**	**2020**	**2030**
CO_2	28 500	28 000	27 700	27 500
CH_4	1.94	1.91	0.23	0.23
N_2O	0.23	0.23	0.23	0.22
NO_x	515	489	361	307
PM_{10}	16.5	14.8	8.6	5.1

d. Maritime transport

The calculation of emissions and energy consumption for maritime transport within E-Motion is implanted on the methodology of MOPSEA (Gommers et al., 2007) and Ex-TREMIS (Chiffi et al., 2009). The methodology will be explained concisely in the next paragraphs. For more details, we refer to Annex 1.

The model is built upon three modules: the fleet module which defines the ship categories and their segmentation, the transport activity module which calculates the ship movements and hours of navigation for the different stages, the emission module which provides energy consumption and emission factors for the final calculation to come up with total energy consumption and emission figures.

The sea-going vessels are divided into 10 different ship types (chemical tanker, container vessel, dry bulk carrier, gas tanker, general cargo vessel, LNG tanker, crude oil tanker, passenger ship, reefer and RoRo vessel) and 5 different length classes (<100m, 100-150m, 150-200m, 200-205m, >250m). Other important parameters are the technology class (age of the main engine is set equal to the age of the vessel), fuel type, type of engine, engine efficiency and engine load as these parameters have an effect on the energy consumption and emission factors. The power of the engines is taken from the EMMOSS model (Vanherle et al., 2007). The share of different main engine types per ship type and class are taken from MOPSEA. For the age distribution we used the Ex-TREMIS methodology based on UNCTAD statistics (website UNCTAD, 2010).

Detailed activity data – expressed in hours - per ship type, length class and movement (region specific) were extracted from the MOPSEA model, as well as the technological aspects of the navigation phases (load factor, used fuel type) and the geographical distribution of the movements. The number of ship movements per ship type, length class and type of movement (region specific) were provided by the harbours themselves for several statistical years. Extrapolation to 1990 was done on the basis of statistics of freight and passenger traffic. Extrapolation up to 2030 was done on the basis of foresights for freight and passenger traffic (Vanherle et al., 2007). The model makes it also possible to take into account changes in ship size and load improvements for future years.

The module for maritime transport is inspired by the EMS protocols (Ministerie van Verkeer en Waterstaat, 2003a, 2003b). All other sources used to provide the maritime module with disaggregated energy consumption and emission factors are presented in Annex 1.

The energy consumption and emission factors per ship visit are region specific because of diverging navigation phases - which have a major impact on these average factors – and different ship characteristics, e.g. size. In Table XI we present as an example the average main engine CO_2, NO_X and SO_2 emission factor for the in and out movement of container and RoRo vessels (150-200 m) for the harbour of Antwerp from 1990 up to 2030.

Table XI: Average main engine CO_2, NO_X and SO_2 emission factors for containers and RoRo vessels (150-200 m) for the harbour of Antwerp
(movement in + out)(kg/visit)

Ship type	Pollutant	1990	2000	2010	2020	2030
Container	CO_2	691	642	655	654	654
	NO_X	21.3	19.8	19.0	18.0	17.9
	SO_2	3.96	8.39	6.26	6.31	6.31
RoRo	CO_2	1088	1033	964	958	958
	NO_X	25.8	26.0	23.3	21.3	21.3
	SO_2	3.94	9.89	9.13	9.24	9.24

In spite of the technological improvement in the energy efficiency of the vessels, there is a slight increase in the CO_2 emission factor for container vessels between 2000 and 2010. The energy demand per ship type is higher for the year 2010 because of different (longer) navigation movements. The NO_X exhaust emission factor of main engines increases for engines built up to 1990 due to efficiency improvements. This effect is more explicit for 4-stroke engines, which results in an increase in the NO_X emission factor between 1990 and 2000 for RoRo vessels in the harbour of Antwerp. The increase in SO_2 emissions between 1990 and 2010 is due to the use of heavy fuel oil for manoeuvring activities by ships built after 1985 instead of diesel oil.

For this project, we developed the maritime module within E-motion, but we did not calculate emissions from maritime transport for the different LIMOBEL scenarios. However, scenario calculations were performed for the Belspo project SHIPFLUX (SHIPFLUX, 2011).

e. Emissions during the production and transport of energy carriers

To assess the total environmental impact on air pollution and to avoid misjudgement during comparison of different motor fuel technologies, one also has to take into account the emissions released during production and transport of the different energy carriers.

To quantify these indirect emissions we updated and extended the indirect emission module of VITO's E-motion model. This module includes the following pollutants: CO_2-eq. (CO_2, CH_4, N_2O), NO_x, PM, NMVOC and SO_2. The basic formula is a multiplication of the energy consumption of road vehicles (MJ per energy carrier) by specific emission factors per energy carrier (g/MJ). We aspired to consider a variation into indirect emission factors over the time period 2010-2030.

For greenhouse gasses we applied JEC (2008) as the main reference for most energy carriers. However, for electricity we based ourselves on VITO's expertise (Lodewijks, 2010). For other pollutants we consulted den Boer et al. (2008) for conventional fuels, Boureima et al. (2009) for biofuels and biogas and Lodewijks et al. (2009) and Lodewijks (2010) for electricity. Gaps were completed with figures from SUSATRANS (De Vlieger et al., 2005).

Table XII gives an overview of CO_2-equivalent, NO_x and PM emissions released during the production and transport of different energy carriers. The table also mentions the raw materials energy carriers are made of. For some this is a result of a mix of various materials. The typical mix for biofuels, biogas, electricity and hydrogen in Belgium has been determined within the BIOSES project (Pelkmans et al., 2011).

Table XII: Emission factors related to production and transport of energy carriers (Belgian market)
(g/MJ)

Energy		CO_2eq			NOx			PM		
carrier	Source	2010	2020	2030	2010	2020	2030	2010	2020	2030
diesel	crude oil	14.5	16.0	17.5	0.021	0.018	0.018	0.002	0.002	0.002
petrol	crude oil	12.9	14.6	16.4	0.026	0.022	0.022	0.003	0.003	0.003
LPG	crude oil	8.1	8.5	8.9	0.020	0.017	0.017	0.002	0.002	0.002
kerosene	crude oil	14.2	16.1	18.1	0.299	0.256	0.256	0.002	0.002	0.002
diesel oil	crude oil	11.5	12.7	13.9	0.017	0.014	0.014	0.002	0.002	0.002
HFO	crude oil	10.1	11.3	12.6	0.017	0.014	0.014	0.002	0.002	0.002
biodiesel	mix	44.6	35.3	32.8	0.143	0.090	0.036	0.033	0.021	0.008
FT-diesel	farmed wood		6.9	6.9	0.101	0.063	0.025	0.021	0.013	0.005
bio-ethanol	mix	40.8	33.9	27.0	0.178	0.111	0.044	0.192	0.120	0.048
CNG	natural gas	12.6	15.0	17.4	0.011	0.011	0.011	0.001	0.001	0.001
biogas	mix	20.5	18.6	16.7	0.022	0.014	0.005	0.005	0.003	0.001
electricity	mix	85.0	97.0	109.0	0.079	0.060	0.045	0.001	0.001	0.003
hydrogen	mix	112.8	139.0	126.1	0.078	0.084	0.090	0.003	0.005	0.007

For conventional fuels and CNG we expect an increase of the emission factors for indirect greenhouse gas emissions. The epoch of easy accessible and cheap crude oil and natural gas is coming to an end. In addition, it becomes more and more difficult for the production to follow the demand. Therefore, more unconventional and hardly reachable sources of oil have to be exploited, such as crude oil of the polar region, ultra-heavy crude and tar sand (Canada).

For biofuels and biogas we expect emissions of both greenhouse gases and air pollutants have a potential to decrease due to the use of more efficient and cleaner tractors and transport and the further optimisation of the production process of the energy carrier.

For electricity the increase in greenhouse gas emission factors is due to the hypothesis that nuclear power plants are fading out gradually between 2015 and 2025 (Lodewijks et al., 2009).

For more details on the assumptions and a detailed overview of the emission factors for CO_2, CH_4, N_2O, NO_x, PM, NMHC en SO_2, we refer to the BIOSES project (Pelkmans et al., 2011).

Within the LIMOBEL project model runs with PLANET were performed with updated emission factors for conventional fuels only, as the emission factors for the other energy carriers were still under development. The indirect emissions related to the production of electricity are based on the models of the Federal Planning Bureau.

Within the PROLIBIC project PLANET model runs are scheduled with the whole updated series of indirect emission factors.

3.4.2. External costs

The previous section dealt with the calculation of Belgian transport emissions. Estimating external costs of transport is another important part of the modelling chain, as it encompasses emissions being translated to a cost for society.

Recently, researchers have shown an increased interest in external costs from transport. Most studies have been carried out for Europe as a whole, or with little inter-country differences (ExternE, 2005; NEEDS, 2007b; IMPACT, 2008). The purpose of this part of the LIMOBEL project is to perform a detailed assessment of marginal external costs (MEC) of transport in Belgium, in order to provide them as inputs in the PLANET model. We particularly focus on the human health impacts of transport air pollution ($PM_{2.5}$ and NO_x). Impacts from other pollutants and other damage classes are only briefly discussed, based on a literature review. This section provides a summary of the methodology used, followed by an overview of the results. For a broader discussion of the methodology and the results of this analysis, we refer to Annex 2.

a. Methodology

Regarding the human health impacts of $PM_{2.5}$ and NO_x air pollution, a detailed analysis was performed based on the impact pathway approach (ExternE, 2005). The reason for doing our own calculations for $PM_{2.5}$ and NO_x lies in the variation of the background concentrations. In other words, we wanted to predict how the marginal external air pollution cost changed, following a variation in general air quality. Therefore, the sequence followed in the impact pathway framework (ExternE, 2005) was applied. As to that, the air quality model BelEUROS was used in order to calculate concentration levels on a 15 by 15 kilometre grid, converting Belgian emission data, including transport emissions from the E-motion emission model. Population density maps were then used so as to estimate the number of people exposed to certain concentration levels. In a third step, the impacts on human health were estimated based on a set of concentration-response (CR) functions. In a final step, the health effects (e.g., in terms of years of life lost) were monetised with a view to obtain external costs.

The external cost calculation for human health impacts was started from the notion that marginal cost figures can only be derived when both a baseline scenario (business-as-usual = BAU) and an alternative scenario (with lower transport emissions) are compared. This was done for three scenario years: 2007, 2020 and 2030. For each of these years the difference between the two scenarios is that the latter starts from a changed transport emission level of one particular pollutant. The outcome of the exercise was a difference in external costs between the two scenarios. This result was then divided by the initial emission difference in order to derive the marginal external cost of each pollutant. This procedure was followed for the two major transport pollutants $PM_{2.5}$ and NO_x. For the other transport pollutants like SO_2, NMVOC and PM_{10}, cost figures will be reported, based on the available literature.

The remainder of this section provides more information on the application of the five steps adopted in the impact pathway approach.

Behind the BAU and alternative scenarios, there are multiple assumptions concerning vehicle fleet, kilometres, activity location and other parameters. That is why each scenario resulted in a separate set of *emissions* (see also Figure C and D of Annex 2).

Each of the non-BAU scenarios was assumed to contain 20% less transport emissions ($PM_{2.5}$ or NO_x) compared to the baseline. The BelEUROS air quality model was then applied in order to estimate the *concentration* differences emerging from this emission difference. Five concentration pollutants were studied: primary $PM_{2.5}$ and PM_{10}, nitrate and sulphate aerosols <2.5µm, and ozone. In the remainder of this report, these are abbreviated to '$PM_{2.5}$ pr', 'PM_{10} pr', 'nitr $_{2.5}$', 'sulph $_{2.5}$' and 'O_3', respectively. The result of this step was a concentration level on a 15 by 15 km grid for each of these five pollutants.

In a third step, detailed European population maps (also 15x15 km, based on the Census 2001 from Eurostat) were used in order to estimate the *number of people exposed* to the concentration levels. Only people living in Belgium and parts of the neighbouring countries (Germany, France, Luxemburg, The Netherlands and UK) were considered, as the majority of the impacts is believed to occur in this area. This corresponds with the 'hot spot' area defined in BelEUROS (see Figure K in Annex 2). Furthermore, a Western European population growth rate was taken into account, based on the population outlook of the Belgian Federal Planning Bureau (FPB, 2009).

In the penultimate step, the *impact* (i.e., the amount of years of life lost/sick days/hospital admissions/etc.) resulting from the exposure to the concentration changes, was calculated. Therefore, the DALY calculator tool was applied, containing large sets of CR functions and building on European projects like ExternE (2005), CAFE (2005a) and NEEDS (2007a). For an exhaustive list of the end points included in our study, supplemented with their relative risk factor or impact function, we refer to Table ii in Annex 2. Please note that concentrations of

$PM_{2.5}$ are both weighed by the CR functions of $PM_{2.5}$ and PM_{10}, as $PM_{2.5}$ is a subset of PM_{10} and double counting is avoided (see section 3.1.4 in Annex 2).

The final step is then the *monetary valuation* of the end point effects calculated in the previous step. Table iii in Annex 2 provides a clear overview of the monetary values that were used. For example, a respiratory hospital admission was valued at 4,856 EUR, whereas each year of life lost from an acute child death from PM_{10} exposure was valued at 66,569 EUR (both in EUR_{2009}). These numbers were based on the figures described in NEEDS (2006), but further took into account the actualisations proposed in NEEDS (2009) and specific recommendations for Belgium in Franckx et al. (2009).

We were not able to distinguish between a tonne of pollutant emitted in urban areas versus rural areas or highways. Instead, we worked with the total marginal emission change throughout the whole of Belgium. Consequently, the external cost figures presented here represent a value per tonne, averaged over all types of emission locations. Note that the scope of this study includes all transport modes on Belgian territory, going from road transport, railway transport, inland navigation and sea shipping between the Belgian ports, to the landing and takeoff cycle for air traffic.

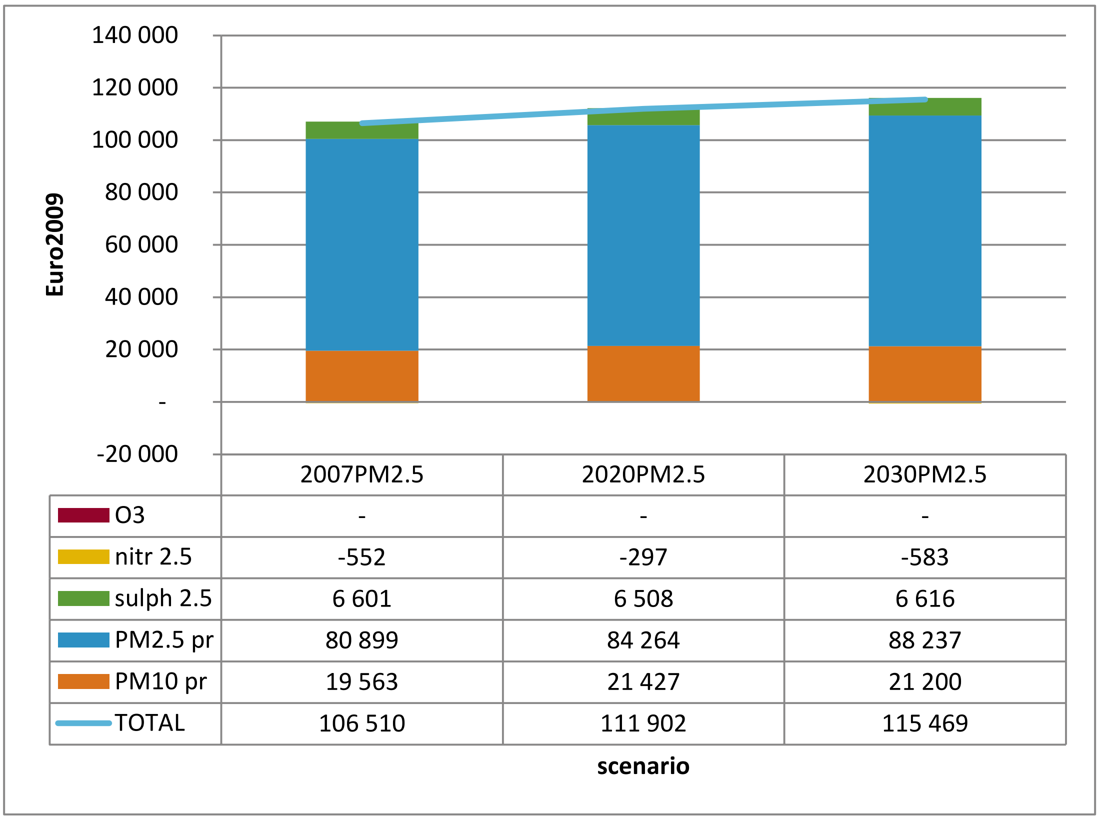
Marginal external costs from damage to buildings, climate change and noise were examined as well, although rather briefly and based on a literature review.

b. Results

The resulting external cost per tonne of transport-related $PM_{2.5}$ emissions ranges from 107 kEUR (2007) over 112 kEUR (2020) to 115 kEUR (2030). The increasing trend can be attributed completely to the projected demographic evolution. From Figure 15, it is clear that the vast majority (94-95%) of $PM_{2.5}$ emissions acts through primary $PM_{2.5}$ (and thus also PM_{10} pr) concentrations. The remaining 5-6% should be ascribed to the formation of sulphate aerosols. All concentration pollutants have a positive sign, except the nitrate fraction. However, these values are too small to be considered as an important external benefit.

The results for $PM_{2.5}$ are plausible in the light of the ExternE results found by Friedrich & Bickel (2001) and the numbers published in IMPACT (2008). They are somewhat lower than the figures in MIRA (2010). However, this could be attributed to the higher resolution concentration and population maps used by their IFDM-RIO model chain.

Figure 15: External cost per tonne of $PM_{2.5}$ emitted in Belgium (by source)



	2007PM2.5	2020PM2.5	2030PM2.5
O3	-	-	-
nitr 2.5	-552	-297	-583
sulph 2.5	6 601	6 508	6 616
PM2.5 pr	80 899	84 264	88 237
PM10 pr	19 563	21 427	21 200
TOTAL	106 510	111 902	115 469

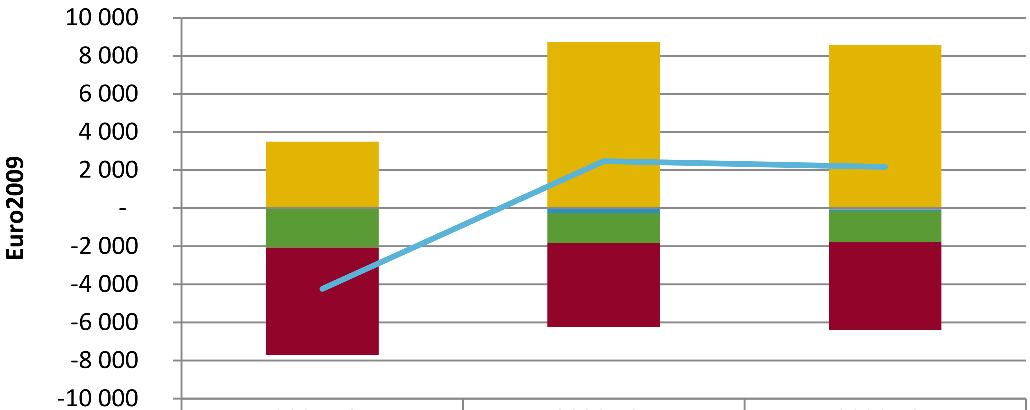
For 2020, 8% of the MEC is attributable to population growth since 2007. Moreover, 11% of the total impacts in 2030 can be ascribed to population growth over the period 2007-2030. This implies that without the projected demographic expansion, the MEC for $PM_{2.5}$ would have been relatively flat over time.

Furthermore, a distinction was made between emissions affecting domestic (Belgium) and foreign areas (i.e., areas in hot spot except Belgium). We find that 25% of total MEC is attributable to impacts taking place abroad. For more information on this split, we refer to Figure Q in Annex 2.

The MEC from NO_x emissions amounts to 2.5 and 2.2 kEUR for the years 2020 and 2030, respectively. However, for 2007 the model results in a MEC of -4.2 kEUR, i.e. a marginal external benefit. In 2007 the marginal external benefit from ozone and sulphate aerosols completely outweighs the MEC originating from the formation of nitrate aerosols. For the years 2020 and 2030, the image is different in the sense that the marginal external benefit from sulphate aerosols and ozone is no longer large enough to compensate for the increased MEC from nitrate aerosol formation. More information on the complex relationship between NO_x emissions and concentrations of ozone and sulphate aerosols can be found under section 3.1.6 of Annex 2.

The resulting numbers are quite new in the light of existing literature, as it is the first time such a detailed computation was executed on a country scale. Still, the results could be compared to the numbers found in the recent MIRA (2010) study, with a MEC for NO_x of -5.3 kEUR and +4.0 kEUR, for Flemish emissions in 2007 and 2020, respectively. However, these numbers can only be compared if one acknowledges that there still exist three large differences between the two project setups. First of all, a MEC for Flemish emissions (MIRA) is not the same as a MEC for emissions in Belgium (LIMOBEL), as population densities are different. Secondly, the emission data for Flanders used in MIRA (2010) were not equal to the IIASA prognoses used in the current study. Finally, the emission sector definitions in MIRA (2010) do not allow to focus on transport as a strictly separate sector.

Figure 16: External cost per tonne of NO_x emitted in Belgium (by source)



	2007NOx	2020NOx	2030NOx
O3	-5 655	-4 416	-4 610
nitr 2.5	3 472	8 707	8 562
sulph 2.5	-2 055	-1 573	-1 658
PM2.5 pr	11	-206	-65
PM10 pr	-10	-48	-69
TOTAL	-4 238	2 466	2 160

scenario

The impact from population growth since 2007 amounts to 8% and 16% for NO_x emissions in 2020 and 2030, respectively.

Additionally, we found that the MEC from NO_x, affecting domestic areas (i.e., Belgium), is negative for all years. This domestic marginal external benefit is further expanded by the effects on foreign areas in 2007, whereas it is more than compensated for in 2020 and 2030. Overall, the majority of the MEC from NO_x emissions can be attributed to effects in foreign areas rather than Belgium. More details on the geographical split can be found in Annex 2.

As already mentioned, the recent study executed for MIRA (2010) estimates MEC figures as well, for emissions in Flanders instead of Belgium. We suggest to use the numbers presented there for the evaluation of emissions to air other than $PM_{2.5}$ and NO_x. Regarding air pollution effects to building materials and greenhouse gas emissions, we resort to the literature as well (see section 3.2 and chapter 4 of Annex 2).

Table XIII presents a summary of the MEC figures for a set of pollutants and scenario years, all in EUR_{2009} terms. Please note that the evolution of future real income is not yet accounted for. Regarding air pollutants, it should be mentioned that only marginal impacts on human health are included, except for SO_2, where the marginal cost for material corrosion is accounted for as well.

Table XIII: Summary marginal external costs

	Marginal EC [EUR/tonne]			
Emitted Pollutant	**2007**	**2020**	**2030**	**Source**
$PM_{2.5}$	106,510	111,902	115,469	LIMOBEL
PMcoarse	24,393	26,771	no data	MIRA (2010)
NO_x	-4,238	2,466	2,160	LIMOBEL
SO_2	7,712	9,946	no data	LIMOBEL, MIRA (2010)
NMVOC	6,613	6,716	no data	MIRA (2010)
CO_2 equivalents				
Low	7	18	23	
Central	26	42	57	IMPACT (2008)
High	47	73	105	

3.4.3. Links to the other LIMOBEL model components

The E-motion module provided updated fuel efficiency and exhaust emission factors (CO, CO_2, NO_x, $PM_{2.5}$, NMVOC, SO_2, N_2O, CH_4, NH_3, NO_2 and Pb) for the PLANET model for all transport modes. Time horizon was 2000 up to 2030.For road transport disaggregated figures were given per vehicle type, fuel type, road type and technology generation (euro standards). For the other modes fleet consumption factors and fleet emission factors were generated making only a distinction between passenger and freight transport. For rail we further split into diesel and electric traction. We provided two sets of figures (baseline versus policy scenario) to allow PLANET to calculate scenarios taking into account technological improvements in heavy duty vehicles and non-road transport. For conventional fuels (petrol, diesel, LPG, gasoil, kerosene and heavy fuel) updated figures for indirect emissions were also transferred. Furthermore, VITO's new insights into marginal external costs per tonne were integrated in PLANET. As a result, PLANET can compute different scenarios taking into account the latest knowledge on fleet composition, energy consumption and emission factors and marginal environmental cost.

For the NODUS model aggregated figures for road transport making only a distinction between cars, Light Duty Vehicles and Heavy Vehicles, were sufficient. These figures could give input to calculate the transport costs (fuel consumption figures) and the geographically distribution of the emissions.

Furthermore, NODUS could give figures on changes in average speeds driven on the different road. E-motion could process this information to adjusted emission factors under a given policy scenario.

3.5. Simulations

In this section we use our modelling framework to determine the impacts of two pricing scenarios on transport, the environment and social welfare. The pricing scenarios were chosen after consultation of the follow-up committee. They consist of the introduction of a kilometre charge on road transport. In the first scenario this charge is only imposed on trucks. In the second scenario, the charge has to be paid by all road vehicles. A more precise definition of the two scenarios is given below. This is followed by the presentation of the reference scenario that will be used as a point of comparison. Next, we turn to the impacts of the two pricing scenarios.

3.5.1. Definition of the alternative scenarios

While in both scenarios a kilometre charge is introduced, they differ in terms of the vehicle types that are subject to the charge. In scenario LIM1 the charge is levied only on heavy duty vehicles (HDV). It is differentiated between the peak (P) and the off-peak (OP) period and applies on the complete road network as from 2009.

The second scenario (LIM2) considers a kilometre charge on trucks (HDV), vans (LDV) and cars. The charges differs according to the vehicle type and period of travel.

Table XIV: Definition of the alternative scenarios

Alternative scenario	Transport mode	Date of implementation	Level of the road tax
LIM1	HDV	from 2009	P = 0.30 EUR/km OP = 0.07 EUR/km
LIM2	HDV, LDV & CAR	from 2009	HDV: P = 0.30 EUR/km OP = 0.07 EUR/km LDV: P = 0.24 EUR/km OP = 0.06 EUR/km CAR: P = 0.14 EUR/km OP = 0.02 EUR/km

In both cases, the introduction of the kilometre charge is compensated by the suppression of fixed taxes (licence, traffic tax and eurovignette for HDV; licence and traffic tax for cars & LDV). Other transport taxes or subsidies are assumed not to change. Any remaining budgetary impact is taken to be neutralised via general tax instruments (cf. infra).

The year 2009 was chosen to be compatible with the network model used by FUCAM. The year itself is not of particular interest. Indeed, as concerns the impact of the alternatives, we are more interested in the variations with respect to the reference scenario than in the values themselves.

3.5.2. Description of the Reference scenario (REF)

The reference scenario (REF scenario)[6] assumes a continuation of current transport policies and the implementation of decided European policies as from end 2008 such as new emissions standards for motor vehicles and the introduction of biofuels[7]. It is based on the November 2007 projections of the European Commission for energy prices (published in April 2008) and on the projections of the PRIMES model for the energy mix in Belgian electricity production (SPF Economie, 2009; Bossier et al., 2008). In these projections it is assumed that the crude oil price will be 63% higher in 2030 than in 2005 in real terms. As regards the infrastructure policy, the REF scenario presupposes a constant capacity for the road infrastructure. For rail and inland navigation, the existing network capacity is taken to be large enough to accommodate additional transport while keeping speed constant. The macroeconomic projections underlying the scenario are taken from HERMES[8] (until 2020) and MALTESE[9] (from 2021 to 2030). Given these assumptions, the REF scenario projects a substantial growth in both freight and passenger transport in Belgium (Table XV).

The total number of passenger-km increases by 31% between 2005 and 2030. The highest increase (35%) is recorded for ‘other’ purposes (shopping, leisure, etc.), followed by school trips (36%) and commuting (18%). The study considers six transport modes for passenger transport: non-motorised transport, rail, car with 1 passenger (car solo), car with at least 2 passengers (car pool), bus/tram/metro and motorcycle. In 2005 the car was dominant for all trip purposes, with a share of

[6] The REF scenario is based on Hertveldt et al. (2009). The results presented in that publication do not yet include the new vehicle stock module and the updated data on emissions caused by transport activity and on the environmental marginal external cost. The reference scenario presented in that publication is therefore slightly different from the one discussed here.

[7] Elaborated end 2008, the REF scenario does not yet include the objective of 10% of renewable energy in the fuel consumption of transport (directive adopted in April 2009).

[8] Bureau fédéral du Plan (2008), extended to 2020 for internal use.

[9] Conseil Supérieur des Finances, Comité d’étude sur le Vieillissement (2008).

approximately 84%. This share is not expected to change by 2030. However, the share of cars with at least 2 passengers should fall, while that of cars with 1 passenger should rise. The share of rail should grow slightly, while that of bus/tram/metro should fall. The other modes should remain relatively unimportant.

Table XV: Transport projections between 2005 and 2030 – Reference scenario

	2005	2030	Increase (in %)
Passenger transport			
Passenger-km in Belgium (billion)			
Commuting	34	40	18%
School	8	11	36%
Other purposes	83	112	35%
Total	125	163	31%
Share of transport modes in passenger-km in Belgium			
Car with 1 passenger (Car solo)	52%	61%	
Car with at least 2 passengers (Car pool)	32%	25%	
Train	6%	7%	
Bus/tram/metro	6%	4%	
Non-motorised	2%	2%	
Motorcycle	1%	1%	
Freight transport			
Tonne-km in Belgium (road, rail, inland navigation)(billion)			
National	31	44	40%
From the rest of the world to Belgium	14	28	99%
From Belgium to the rest of the world	14	24	73%
Transit without transhipment	10	15	52%
Total	70	112	60%
Modal share in tonne-km in Belgium			
Truck	72%	67%	
Van	3%	3%	
Train	12%	15%	
Inland navigation	13%	14%	

Source: PLANET v2.0

The total number of tonne-km transported in Belgium by means of road, rail and inland navigation increases by 60% between 2005 and 2030. The highest growth should take place for international transport to and from Belgium, which is expected to increase by 99% and 73%, respectively. Transit should grow by 52%, while national transport should rise by 40%. There should be a shift from the road modes (trucks and vans) to rail and inland navigation. The road modes will remain dominant, however, with a share at 70% in 2030.

The projected growth of passenger and freight transport should further deteriorate traffic conditions in Belgium. This is reflected in a projected fall in average road speed. In 2030, the average road speed in the peak period will be 31% lower than in 2005; in the off-peak period it will fall by 17%. This implies a strong increase in the marginal external congestion costs. Since the study assumes a constant road infrastructure capacity, the projected evolution of the congestion costs should be seen as an upper limit. However, even with an expansion of capacity, congestion is expected to grow.

Table XVI shows the ratios of the taxes and of the marginal external costs (congestion + direct exhaust and non-exhaust emissions) related to transport for the reference scenario. In 2005, the ratios show that the taxes do not fully internalise the marginal external costs. In the peak period the taxation is too low, independently of the mode of transport. In the off-peak period, the level of taxation is too high for cars, but remains too low for HDV and LDV. Ceteris paribus, the level of taxation is worsening in 2030 with respect to the marginal external costs which increase due to the expansion of transport activity (freight and passenger transport).

Table XVI: Taxes versus marginal external costs – Reference scenario
(congestion + direct exhaust and non-exhaust emissions)

		2005		2030	
		tax/100vkm	**tax/external costs**	**tax/100vkm**	**tax/external costs**
Peak	Car	9.03	25%	7.30	6%
	HDV	10.54	15%	9.24	4%
	LDV	4.00	7%	3.38	2%
Off-peak	Car	9.03	148%	7.30	47%
	HDV	10.54	92%	9.24	28%
	LDV	4.00	44%	3.38	15%

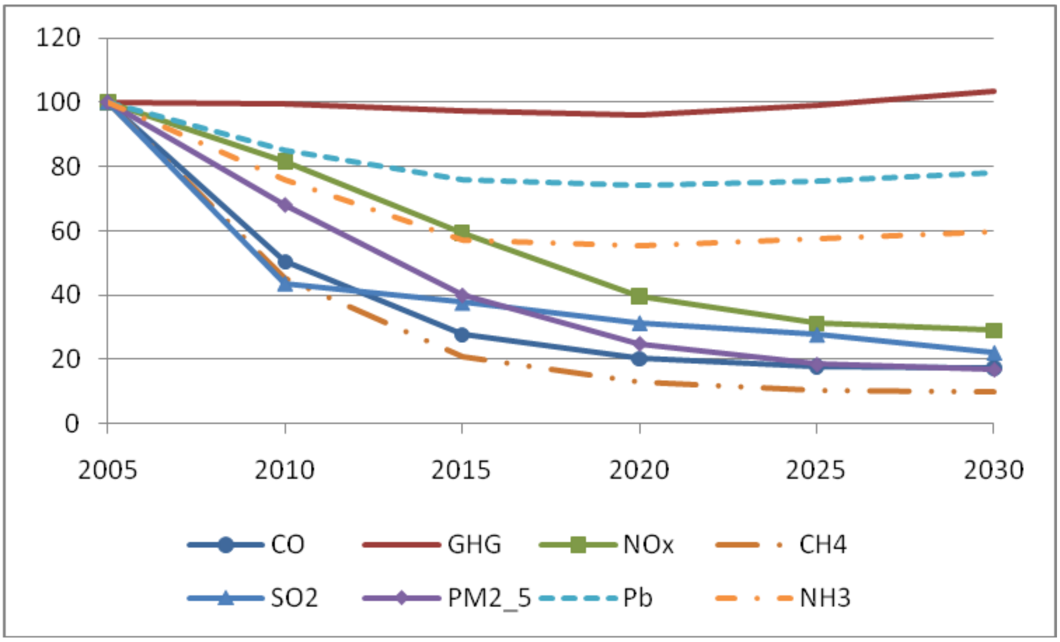
Source : PLANET v2.0

As concerns the evolution of the (direct) emissions related to the transport activity (Figure 17) the implementation of environmental policies will be successful in reducing emissions of the traditional air pollutants (CO, $PM_{2.5}$, NMVOC, NO_X and SO_2), even when taking into account the growth in transport. For the emission factors, the PLANET model based itself on the base scenario of the E-Motion model (Section 3.4.1). Greenhouse gas emissions will increase, however, by 3% between 2005 and 2030. In these cases, the increased fuel efficiency of vehicles is offset by the growth in transport. In the reference scenario described in Hertveldt et al. (2009), the development of greenhouse gas emissions was calculated with PLANET v1.0. It translates into an increase by 17.6% between 2005 and 2030. There are two main reasons for the significant difference between the two 'reference' projections. Firstly, the insertion of the vehicle stock module in PLANET v2.0 allows being more accurate on the evolution of emissions factors per type of vehicles (fuel and size) and per Euro standard, whereas PLANET v1.0 relies only average emissions factors for each type of car technology (diesel, gasoline, etc.). Secondly, PLANET v2.0 benefits from the updated emission factors computed by the VITO in the framework of the LIMOBEL project. These emission factors have significantly diminished, and more particularly for HDV (see Section 3.4.1.a).

As concerns the energy used by the transport sector, the consumption of fuel for the transport activity increases by 14.4% from 2005 to 2030[10]. Looking at freight transport and passenger transport separately, the increase for passenger transport (10.2%) is lower than that for freight transport (25%). For the consumption of electricity, the computations are not implemented in PLANET.

Figure 17: Evolution of the direct emissions related to transport – Reference scenario

Freight and passenger transport; 2005 = 100



Source: PLANET v2.0

[10] The consumption of fuel by bus/tram/metro is not included (but it is only 2% of the consumption of diesel by the transporters)

Figure 18: Evolution of the external environmental costs related to transport – Reference scenario

MEUR

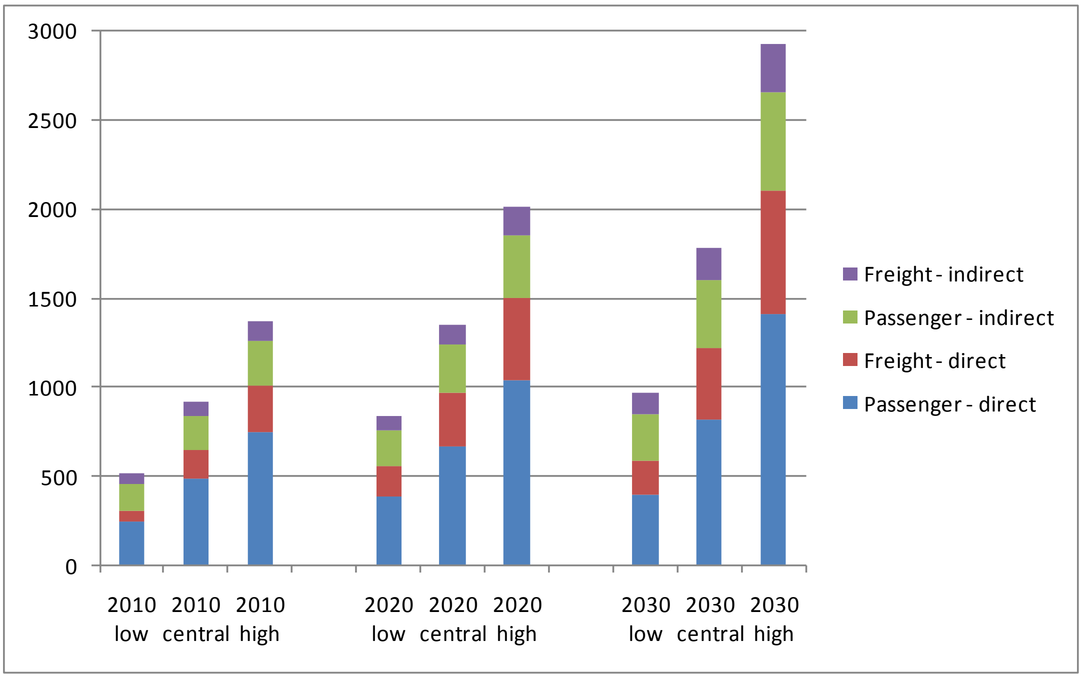


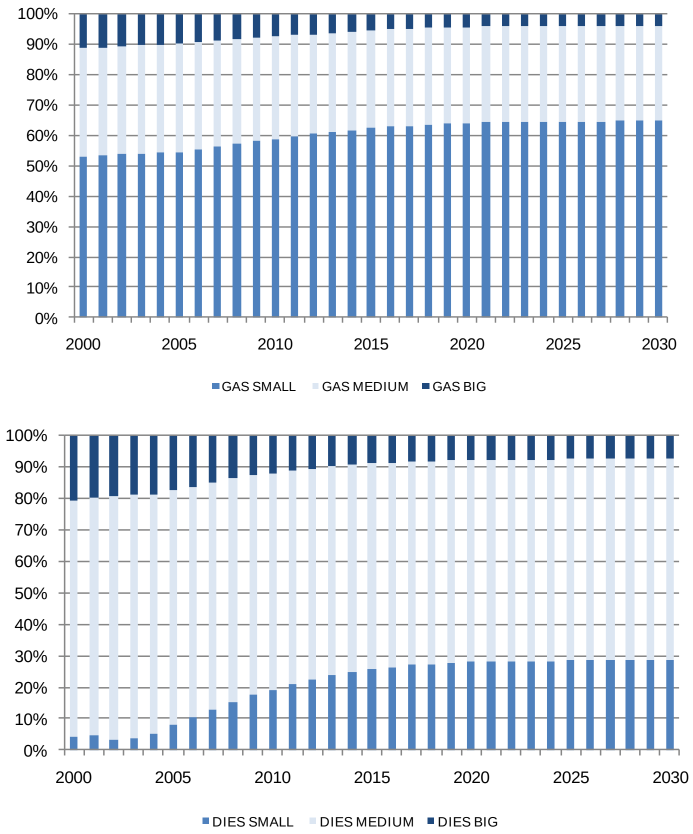
Figure 18 gives the evolution of the external environmental costs between 2010 and 2030. A distinction is made between the costs related to the direct and indirect emissions of passenger and freight transport. The indirect emissions are those that are caused by the production and transport of the fuels and electricity used by transport. For the electricity production the figure assumes a gradual phase out of nuclear energy and the implementation of the EU climate and energy package of 2008 for Belgium. The damage costs per tonne of pollutants that underlie these results are reported in Table XIII. For the traditional pollutants the model also assumes that these values increase with real GDP per capita. The figure considers a low, central and high damage cost for greenhouse gas emissions, that increase over time (Table XIII.).

In 2010 the environmental costs range between 520 and 1370 MEUR. In 2030 they are projected to be 88% to 114% higher than in 2010 depending on valuation for GHG emissions (94% increase if central value is used) and this in spite of the fall in the emissions of all pollutants except the GHG (Figure 17). The growth is due to the increase in damage costs over time (due to changes in background concentrations, population and GDP per capita).

The direct environmental costs account for 60% to 75% of the total environmental costs. The share of the environmental costs of freight transport grows between 2010 and 2030 (from 26% to 33% in the central scenario). Over time greenhouse gas emissions are projected to account for an increasing share of the environmental costs (from 52.7% in 2010 to 69.1% in 2030 for the central scenario).

As a final result for the reference scenario, Figure 19 presents the evolution of the repartition of the vehicle-km (gasoline and diesel) according to the size of the vehicle. This decomposition is made available thanks to the vehicle stock module. The trend shows an increase (resp. decrease) in the vehicle-km driven by small (resp. big) cars.

Figure 19: Evolution of the repartition of the vehicle-km (gasoline and diesel) according to the size of the vehicle



3.5.3. Results of the simulations

a. Transport

This section presents the impacts of the two alternative scenarios (LIM1 & LIM2) on passenger transport (Table XVII), freight transport (Table XIX), speed, external marginal cost and tax revenues (Table XX), and on the emissions generated by transport (Table XXI). The results are presented for the year 2030. Each alternative scenario is compared (in %) to the REF scenario.

Passenger transport

As concerns passenger transport (Table XVII), introducing a kilometre charge on heavy duty vehicles (LIM1) has no effect on the passenger-km and on the vehicle-km. This is explained by the average speed (Table XX) which does not change with respect to the REF scenario. The vehicle stock for passenger transport also remains similar to the one obtained in the REF scenario, as no parameters affecting the vehicle stock are modified by a kilometre charge on HDV only.

Table XVII: Impact of the alternative scenarios on passenger transport in 2030 (difference in % w.r.t. the reference scenario)

		LIM1	LIM2	REF
Passenger-km (mio.)	Total	0%	-1%	162628
	School	0%	1%	10751
	Commuting	0%	0%	39961
	Other	0%	0%	111916
	Foot/bicycle	0%	-12%	3955
	Rail	0%	5%	11114
	Car solo	0%	-4%	99231
	Car pool	0%	4%	40470
	Bus/tram/metro	0%	20%	6311
	Motorcycle	0%	0%	1547
	Peak	0%	-2%	45471
	Off Peak	0%	1%	117157
Vehicle-km (1000 per day)	Peak –Car	0%	-10%	79219
	Peak –Bus/tram/metro	1%	45%	208
	Peak – MOTO	0%	2%	990
	Off- Peak Car	0%	-1%	232684
	Off-Peak Bus/tram/metro	0%	-1%	639
	Off peak MOTO	0%	-1%	3249

Source: PLANET v2.0

Charging all road transport modes, as in LIM2, leads to a total number of passenger-km which decreases by 1% (Table XVII). This evolution is explained by the decrease in passenger-km attributed to the mode “car solo” (-4%). The introduction of a kilometre charge on cars leads to a modal shift towards rail transport (+5%) and bus/tram/metro (+20%). The decrease in the share of pkm realised by foot and bicycle (and absorbed by BTM) is explained by the higher average speed on the road. Furthermore, differentiating the level of the tax according to the period leads to an increase (resp. decrease) in passenger-km during the peak (resp. off-peak) period (+1% for off-peak and -2% for peak). As for the vehicle-km, the share of cars decreases in the peak period, and also – but less markedly – in the off-peak period. The number passenger-km by bus/tram/metro increases in the peak period (+45%).

For the vehicle stock, the introduction of a kilometre charge on car leads to a small reduction in the share of cars using diesel (-0.82 %point) and, respectively, a small increase in the share of cars using gasoline (+0.81 %point). This is explained by the higher relative increase in monetary cost for diesel car compared to gasoline car.

Freight transport

The kilometre charge on HDV (LIM1) has as expected an impact on freight transport (Table XIX). The lower share of tonne-km transported by HDV (-1%) is compensated by an increase in tonne-km transported by LDV (+2%), trains (+2%) and barges (+3%). On the road network, the impact on the total vehicle-km is positive (+1%) due to the increase in LDV (+2% in peak and in off-peak). The total increase in LDV (+289 mio. vehicle-km) is indeed higher than the total decrease in HDV in vehicle-km (-92 mio. vehicle-km). It is worth to note that the tkm transported for transit decreases (-2%). This is due to a loss of competitiveness with respect to neighbouring countries[11].

The alternative scenario LIM2 leads to an increase in tonne-km by 1% (Table XIX). This is explained by the increase in tonne-km for national transport (3%), by the modal shift from LDV (-3%) to HDV (+1%) and by the fact that the average distance for HDV is higher than the average distance for LDV. The share of tonne-km transported by rail has declined (-1%) thanks to the higher average speed on the road (see Table XX). As concerns the vehicle-km, the total number decreases by 2%. This is explained by the fall in the number of LDV (-6% in the peak period and -2% in the off-peak period), which is higher than the increase in the number of HDV (10% in the peak period).

Observations realised in other countries (Switzerland, Germany) have shown that the introduction of a road pricing does not only lead to a modal shift but also to a improved efficiency of road transport through, among others, a higher load charge. The actual methodology implemented in PLANET does not allow to take this impact into account. In the future the load factor will be made endogenous.

Introducing road pricing policies as done in LIM1 and LIM2 leads to a modification of the average monetary costs per tonne-km and of the average speed on the road (presented in Table XVIII). These results are in a second step used as inputs in the

[11] If neighbouring countries also introduce a kilometre charge, this effect should vanish/diminish /reverse according to the level of the road pricing implemented in those countries. In LIM1 and LIM2 we do not take into account any kilometre charge in border countries.

network model (NODUS) developed by the FUCAM. The variation of the average speed (-0.10% in LIM1 and 0.65% in LIM2) is however too small to have an impact on the network model. The impact of road pricing on the network model, trough a modification of the average speed has consequently not been done.

Table XVIII: Outputs from PLANET v2.0 used as inputs for the simulation with NODUS
(difference in % w.r.t. the reference scenario)

	LIM1	LIM2	Reference scenario (level in 2010)
Freight - average monetary cost per tonne-km			
ROAD	12.49%	27.94%	0.022 euro
RAIL	0.13%	0.02%	0.036 euro
IWW	0.00%	0.00%	0.024 euro
Passenger- average monetary cost per passenger-km			
ROAD	0.00%	16.41%	0.16 euro
RAIL	0.15%	-7.54%	0.035 euro
Road speed	-0.10%	0.65%	62.1 km/h

Source: PLANET v2.0

Table XIX: Impact of the alternative scenarios on freight transport in 2030
(difference in % w.r.t. the reference scenario)

		LIM1	LIM2	REF
Tonne-km in Belgium	Total	0%	1%	111857
	National	-1%	3%	43646
	In	1%	-1%	24526
	Out	1%	-1%	28522
	Transit	-2%	-1%	15164
	International	0%	-1%	68211
	HDV	-1%	1%	74313
	LDV	2%	-3%	3935
	Inland Nav.	3%	0%	16084
	Rail	2%	-1%	17524
Vehicle-km in Belgium	Total	1%	-2%	22135
	Peak - HDV	-7%	10%	1273
	Peak - LDV	2%	-6%	3763
	Peak	0%	-2%	5036
	Off-peak HDV	0%	0%	5120
	Off-peak LDV	2%	-2%	11979
	Off-peak	1%	-2%	17099

Source: PLANET v2.0

b. Congestion and tax revenues

The alternative scenario LIM1 has no impact on the average speed. The decrease in the total number of HDV should lead to an increase in the average speed. But this impact is compensated by the rise in the total number of LDV. Although the total number of vehicle-km is higher in LIM1 than in the REF scenario, the speed does, however, not vary because LDV has a lower weight in the speed function[12]. The yearly tax revenues from passenger transport are unchanged and those from the HDV increase by 60%. The changes in taxes generated by LDV and railways are less significant (1% and 2% respectively).

Charging all road modes, as done in LIM2, leads to an increase in the average speed by 22% in the peak period and by 1% in the off-peak period. The external marginal cost of congestion decreases by 32%, thanks to the higher average speed. Not surprisingly, the yearly tax revenues increase significantly, both for passenger and freight transport. This is mainly explained by the revenues from the kilometre charge on the road: +44% for cars, +70% for HDV and + 271% for LDV.

Table XX: Impact of the alternatives on speed, external marginal cost and tax revenues in 2030
(difference in % w.r.t. the reference scenario)

	LIM1	LIM2	REF
External marginal cost of congestion (EUR per car vehicle-km)			
Peak	-2%	-32%	1.19
Off-peak	0%	-1%	0.15
Yearly tax revenues on passengers transport (M EUR)			
Rail	0%	5%	-609.66
Car	0%	44%	8313.38
BTM	0%	16%	-585.84
Moto	0%	78%	60.18
Total	0%	50%	7178.06
Yearly tax revenues on freight transport (M EUR)			
HDV	60%	70%	652.38
LDV	1%	271%	522.65
Rail	2%	-1%	-63.59
Inland nav.	0%	0%	0.00
Total	36%	169%	1111.44

Source: PLANET v2.0

c. Environment

Kilometre charge on HDV only (LIM1) does not influence air pollution much (Table XXI). This is explained by the total vehicle-km which remains unchanged

[12] In the model 1 LDV counts for 1.5 car and 1 HDV counts for 2 cars.

with respect to the REF scenario. Furthermore, the beneficial effect generated by the decrease in HDV is offset by the detrimental effect generated by the increase in LDV.

The kilometre charge on all road modes of transport (CAR, LDV and HDV) in LIM2 leads to a significant decrease in total emissions (from -2% to -8% according to the pollutant, see Table XXI). Total emissions are the sum of direct, indirect and non-exhaust emissions.

As concerns the consumption of energy, the total fuel consumption by the transport sector in 2030 decreases by 3.6% in scenario LIM1 (w.r.t. the reference scenario), with a decrease of 11.8% for freight transport. The effect is insignificant for the fuel consumption by passenger transport. In the alternative scenario LIM2, the fuel consumption for both freight and passenger transport decreases by 21.3% and 10.8%, respectively. The total fuel consumption by the transport sector decreases by 14% (in 2030, again w.r.t. to the reference scenario).

Table XXI: Impact of the alternative scenarios on the emissions in 2030
(difference w.r.t. the reference scenario)

	Direct		Indirect		Non-exhaust		Total emissions	
	LIM1	LIM2	LIM1	LIM2	LIM1	LIM2	LIM1	LIM2
CO	0%	-6%	0%	0%	0%	0%	0%	-6%
CO_2	0%	-7%	0%	-6%	0%	0%	0%	-7%
NO_x	1%	-6%	0%	-5%	0%	0%	1%	-6%
NMVOC	0%	-4%	0%	-7%	0%	0%	0%	-7%
N_2O	0%	-7%	0%	0%	0%	0%	0%	-7%
CH_4	0%	-4%	0%	0%	0%	0%	0%	-4%
SO_2	0%	-7%	0%	-6%	0%	0%	0%	-6%
TSP	0%	0%	0%	0%	0%	-2%	0%	-2%
PM_{10}	0%	0%	0%	0%	0%	-2%	0%	-2%
$PM_{2.5}$	0%	-8%	0%	-5%	0%	-2%	0%	-4%
Pb	0%	-8%	0%	0%	0%	0%	0%	-8%
NH_3	0%	-8%	0%	0%	0%	0%	0%	-8%

Source: PLANET v2.0

A kilometre charge on HDV (LIM1) allows improving the coverage rate of the marginal external costs related to HDV with respect to taxes. In the peak period it goes from 4% in the REF scenario to 16% in LIM1. In the off-peak period it goes respectively from 28% to 42%. This scenario does not affect the coverage rate for the other modes. To charge all modes of transport as done in LIM2 leads to an increase of the coverage rate for each mode. In both alternatives, the level of the taxes remains however too low to internalise fully the marginal external costs.

Table XXII: Impact of the alternative scenarios on taxes and marginal external costs
(congestion + direct exhaust and non-exhaust emissions; 2030)

		Reference		LIM1		LIM2	
		tax/100vkm	tax/external costs	tax/100vkm	tax/external costs	tax/100vkm	tax/external costs
Peak	Car	7.30	6%	7.30	6%	20.04	25%
	HDV	9.24	4%	36.83	16%	36.83	23%
	LDV	3.38	2%	3.36	2%	26.79	22%
Off-peak	Car	7.30	47%	7.30	47%	8.04	52%
	HDV	9.24	28%	13.83	42%	13.83	43%
	LDV	3.38	15%	3.36	14%	8.78	38%

Source: PLANET v2.0

d. Welfare

Table XXIII and Figure 20 present the impact of the alternative scenarios on welfare. Welfare is the sum of consumer surplus, producer surplus, tax revenues from transport activities and environmental benefits. The results are presented in net present value in 2010, with a discount rate of 4%. In both alternative scenarios, the negative impact on welfare (see category E in Table XXIII) is explained by the decrease in the consumer and producer surplus. The impact is more marked in the second alternative scenario (LIM2), due to a kilometre charge on both freight and passenger transport (the loss in surpluses is more significant). Furthermore, the gain in tax revenues does not compensate the loss in surplus. Note that charging both freight and passenger transport (LIM2) has positive effects on the environmental benefits (1471 MEUR). In the first alternative (LIM1), the impact on the environmental benefits is slightly negative (-27 MEUR). This is explained by the increase in vehicle-km for the freight transport.

The above results do not take into account any additional benefits or losses of tax recycling. In this perspective, we assume that recycling is done either by general taxation or by labour taxation. We also assume that general taxation is less distortionary than labour taxation, and that taxation on commuting has the same effect as labour taxation. In Table XXIII, the total welfare impact (including recycling) is then calculated assuming a difference of 1.4 between the marginal cost of public fund in case of general taxation ($MCPF_{GT}$) and in case of labour taxation ($MCPF_{LT}$)[13]. For the alternative scenario LIM1, the impact on welfare including tax recycling remains negative, whatever the way of recycling (general or labour). For the alternative scenario LIM2, the impact on welfare becomes positive if tax revenues are recycled through labour taxation. The latter result shows the

[13] For more details, see Gusbin et al. (2010).

beneficial effect of recycling tax revenues generated by commuting through lower labour taxes (rather than via general taxation). As a final comment, let us highlight the sensitivity of the impact on welfare with respect to the type of recycling. Tax recycling is consequently not trivial and of great importance.

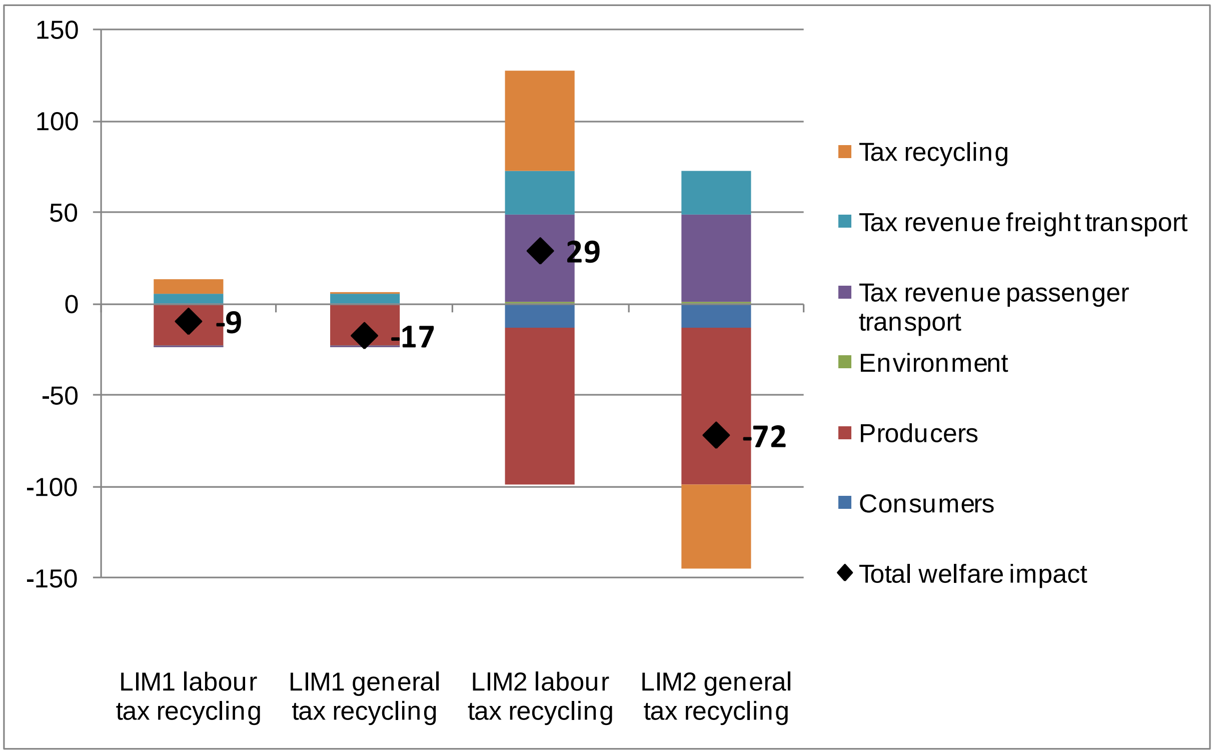
Table XXIII: Impact of the alternatives on welfare for the period 2010-2030 ($MEUR_{2000}$, net present value in 2010) (difference w.r.t. the reference scenario)

		LIM1	**LIM2**
Surplus			
consumer surplus	A	-340	-13442
producer surplus	B	-22567	-85307
Taxes revenues related to transport	C=a+b+c	5598	72135
commuting trips	a	-12	33043
other passenger trips	b	-28	14825
freight	c	5638	24267
Environmental benefits			
Direct + indirect		-27	1471
Direct[a]	D	-23	1016
Welfare impact	E=A+B+C+D	-17332	-25597
IF $MCPF_{LT} – MCPF_{GT} = 1,4$			
- General taxation to offset the budgetary impact	F	16	-46261
- Labour charge to offset the budgetary impact	G	7854	54729
Welfare impact (including recycling)			
- General taxation to offset the budgetary impact	H=E+F	-17316	-71858
- Labour taxation to offset the budgetary impact	I=E+G	-9478	29132

[a] We only take into account the environmental benefits related to the direct emissions, since the indirect emissions are not under the control of the transport users

Source: PLANET v2.0

Figure 20: Impact of the alternatives on welfare for the period 2010-2030 (billion EUR_{2000}, net present value in 2010) (difference w.r.t. the reference scenario)



Source: PLANET v2.0

e. The impact of the alternative scenarios in the network model

The simulations with the network model are based on the inputs of the PLANET model (Table XVIII). These inputs are first, the variation in average monetary cost per tonne-km for freight transport and secondly per passenger-km for passenger transport. The variation in average speed was also communicated but because the impacts are very small (less than 1 km/h), it was not possible to include it in NODUS. We used the changes in the average monetary costs to modify our cost functions. These changes have impacts on different elements in NODUS: the total costs, the tonne-km and passenger-km, the tonnes and passengers and the modal distribution. These different effects are presented below.

Total costs

For the first scenario, for road, there is a km charge only for freight transport and so, as expected, the change in total cost is only present in the freight case.

For the second scenario, the increase in cost is still higher for the freight transport as for the average monetary cost. Moreover, although the rail transport average monetary cost decreases, the passengers total cost increases because of the very high increase in the road passengers average monetary cost.

Table XXIV: Change in costs

	LIM1	LIM2
Freight	10.32%	22.55%
Road	10.74%	23.61%
Rail	9.93%	21.13%
Inland navigation	7.63%	16.93%
Passenger		16.20%
Road		16.36%
Rail		15.95%

If we look at the details of the total cost changes, we observe that changes are more important for road than for the other modes. However, for all the other modes, if we compare the changes in total and average monetary cost, they appear much more impressive for total cost. It can be explained by the change in passenger-km/tonne-km that we will present below.

Transport flows

Table XXV: Change in tonne-km and tonnes

	LIM1	LIM2
Tonne-km		
Road	-1.49%	-3.24%
Rail	9.85%	21.62%
Inland navigation	7.45%	16.36%
Tonnes		
Road	-2.54%	-4.83%
Rail	12.60%	22.00%
Inland navigation	8.75%	18.50%

For freight transport, we can observe that a decrease for the road mode induces an increase in the two other modes, slightly more important for rail than for inland waterways. The changes in the tonne-km can be mainly explained by the changes in tonnes. As expected, the changes are more important for the second scenario due to the higher change in average monetary cost.

Table XXVI: Change in passenger-km and passengers

	LIM1	LIM2
Passenger-km		
Road	0.00%	-0.04%
Rail	-0.13%	24.38%
Passengers		
Road	0.00%	-0.04%
Rail	-0.13%	24.53%

For the first scenario, the changes in average monetary cost for passenger transport are nearly non-existent; so, obviously, there are few effects on the passenger transport. However, for the second scenario, we can observe that changes in passengers and passenger-km are present. If we compare the changes for the road and rail modes, it can appear as disproportionate but the explanation is quite simple: most passengers use the road so, ceteris paribus, a change in passenger number will be less visible for road than for rail transport.

Modal distribution

Table XXVII: Modal distribution tonne-km and tonnes

	REF	LIM1	LIM2
Tonne-km			
Road	83%	81%	80%
Rail	11%	12%	13%
Inland navigation	6%	7%	7%
Tonnes			
Road	81%	79%	77%
Rail	9%	10%	11%
Inland navigation	10%	11%	12%

Table XXVIII: Modal distribution passenger-km and passengers

	REF	LIM1	LIM2
Passenger-km			
Road	88%	88%	86%
Rail	12%	12%	14%
Passengers			
Road	88%	88%	85%
Rail	12%	12%	15%

In general, the higher is the change in road average monetary cost, the higher the modal share of the non-road modes. For passenger transport, as the first scenario has no effect on average monetary cost, the modal distribution stays the same.

4. GENERAL EQUILIBRIUM EFFECTS OF TRANSPORT POLICIES

The Computable General Equilibrium (CGE) model allows to relax the assumption that the evolution of the economy is unaffected by changes in the transport sector (assumption made in PLANET). For this a CGE model for the Belgian economy and its three regions is constructed. The aim is to model both the implications of economic developments on transport use, and the indirect impacts of changes in the transport sector on the economic system. The CGE approach allows for an explicit calculation of the full welfare impacts of policy changes, taking into account the impacts on all economic agents and not only on the transport sector. We started with an overview of the literature on CGE models (see Annex 3). Initially, it was planned to construct a dynamic recursive CGE model. However, for reasons which are explained below, we realised that the construction of a dynamic CGE model was not feasible in the time span of this project. At this stage, the model is therefore static but still remains of great interest for analyzing the impact of policies on transport and on the economy.

A static version with 9 types of households, imperfect competition on the goods market and involuntary employment has been developed, but the policy simulations with this version still present, unexpected (and unexplainable) results. In this report we therefore use a static CGE model with 3 types of households, perfect competition and voluntary unemployment. The static version with 9 types of households should be available by the end of January. The 9 groups will be defined in terms of three criteria: the region (Brussels, Flanders, and Wallonia), the educational level (high and low skilled)[14] and participation on the labour market (active or inactive). The selection of these groups is based on a statistical analysis of the Belgian Household Budget Survey from 2002 to 2006 (Vandresse, 2009; see Annex 5).

4.1. Structure of the CGE model

The CGE model incorporates the following economic agents: different households groups, the domestic production sectors, the trade sectors, the federal and regional governments and the foreign sector. The model is programmed in GAMS and is solved using the PATH solver. The first four sections discuss the modelling approach for the households, the domestic production sectors, the trade sectors and the Belgian governments. Next, the institutional setting of the labour market is

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[14] The low skilled group includes all people with an education up to a secondary school degree.

presented. The last two sections treat the savings and investment decisions and the market equilibrium conditions.

Before we engage in a full description of the model, it may help to summarise the notation of the model. Variables are stated in upper case letters whereas parameters are in lower cases. In some cases, the initial values of the variables are taken explicitly as a parameter. In this case, the original name is preceded by the latter 'b' (from 'base year') and the name is written in lower cases.

Table XXIX: Subscripts associated with the different dimensions

	Subscript	
Sectors	S	See Table XXX
Good (SUT classification)	G	See Table XXXI
Goods (Coicop classification)	C	See Figure 21
Aggregate consumption goods (Coicop)	c2	Durables and energy goods, non-durables
Regions	r,rr or rrr	See Table XXXII
Governments	Gv	Federal, Flemish region, Walloon region, Brussels region, French community, European Union
Tax types	T	Labour and capital taxes, excises, VAT, 'Lump sum taxes', other product related taxes, car registration duties, subsidies
Transport purpose	Mot	Work, school, other
Transport location	L	In Belgium, abroad
Time Period	Pr	Peak, off-peak
Social mode of car transport	Socc	Car solo, Car pool
Mode of road freight transport	M	Heavy duty, light duty, rail, inland navigation (IWW)

The listings of the variables and of the equations of the CGE model are presented in Annex 4.

4.1.1. The households

The CGE model includes different household groups, characterised each by a nested CES utility function which they maximise subject to a monetary budget and a time budget constraint. The groups are defined according to the region of location (Brussels, Flanders, and Wallonia).

a. Household income and time constraint

The current model incorporates the behaviour of one representative household per region. The households earn labour income and capital income, each net of taxes, receive transfers TRF_r from the different governments and pay 'Lump Sum' taxes

LST_r to the different governments. Their wage rate (PW_r) is net of monetary commuting costs (CC_{TOT_r}), while they pay the monetary costs of schooling trips (SC_r) as well. Savings are defined according to a fixed savings rate sav_H. We subtract the values of minimal consumption μ to arrive at disposable money income $Ydisp_r$:

$$Ydisp_r = \left(\sum_{rr} COMM_{r,rr} \cdot \left(PW_r\left(1 - \sum_t \tau y_t^{LAB}\right) - CC_{TOT_r}\right) + \omega_r^K TOTCAPY\left(1 - \tau y_t^K\right) + CPI \cdot TRF_r - CPI \cdot LST_r - SC_r\right) \cdot \left(1 - sav_H\right) - \sum_c \mu_{c,r}^{ener}\, PC_{c,r} - \sum_c \mu_{c,r}^{ndg}\, PC_{c,r} - \sum_c \mu_{c,r}^{dg}\, PC_{c,r}$$

In this equation $COMM_{r,rr}$ is the number of commuters between regions. $TOTCAPY$ is total capital income, which is divided according to fixed ownership share ω_r^K. *CPI* is the consumer price index.

Households are endowed with a fixed amount of time T_r, which they have to allocate between labour, leisure $QCLeis_r$ and time spent on transport (ST_t for schooling trips[15], LT_r for leisure trips and $LABOUR_r.CT_{TOT_r}$ for commuting trips):

$$\overline{T_r} = LABOUR_r\left(1 + CT_{TOT_r}\right) + ST_t + LT_r + QCLeis_r$$

Combining the money and time constraints leads to an expression for disposable extended income $Yext_r$:

$$Yext_r = PCleis_r\left(\overline{T_r} - ST_t\right) + \omega_r^K TOTCAPY\left(1 - \tau y_t^K\right) + CPI \cdot TRF_r - CPI \cdot LST_r - SC_r - SAV_{H_r} - \sum_c \mu_{c,r}^{ener}\, PC_{c,r} - \sum_c \mu_{c,r}^{ndg}\, PC_{c,r} - \sum_c \mu_{c,r}^{dg}\, PC_{c,r}$$

with SAV_H representing total savings and the value of time being defined as:

$$PCleis_r = \frac{\left(PW_r\left(1 - \sum_t \tau y_t^{LAB}\right) - CC_{TOT_r}\right)}{\left(1 + CT_{TOT_r}\right)}$$

which is the wage rate net of taxes and commuting costs. Note that time and monetary commuting costs are expressed as values per commuter.

b. Household Utility

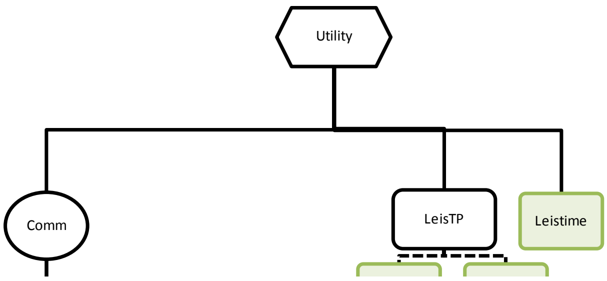
Under the constraint of disposable extended income, households maximise a nested MCES (Keller, 1976) utility function (Figure 21). At the top level the first component of the utility function is a MCES function of leisure time (leistime), leisure transport (LeisTP) and a composite of the other goods and services (Comm). Leisure transport is a composite of trips by different modes and time periods. This function will be explained in a later paragraph. The composite commodity is a MCES function of the composite of non-durable goods (NDG) and the composite of durable goods and energy (DGene). The non-durable goods composite is a MCES function of five types of non-durable goods: health related goods and services (Hea), textile and shoes (Tex), food, drink and tobacco (Food),

[15] One could with some justice argue that the complementarity between labour supply and time spent on schooling trips is in reality only marginal.

household equipment (eqH) and education, communication, culture and others (ser).

The durable goods and energy composite is a MCES function of the consumption of 2 types of durable goods services (Major appliances (Heat) and Other durable goods (DGoth), comprising mainly housing) and of three energy goods (Gas, Electricity and Other energy). The consumption of the durable goods services requires the input of the durable goods themselves, and of a minimum level of energy goods, as modelled by a Leontief function. This way, it is captured that the price of the energy goods may influence the consumption of durable goods. Households can choose to consume more than the minimum amount of energy that is required for the operation of the durable goods. The supplementary energy consumption is included in the energy components of the utility function.

Figure 21: The nesting structure of the first component of the household utility function



In the model code, consumer prices $PC_{c,r}$ are defined as tax inclusive:

$$PC_{c,r} = \ {}_{g} mapH_{g,c,r} PA0_{g,r} \ 1 + \ {}_{t} \tau c_{c,r,t}$$

where $mapH_{g,c,r}$ is a mapping that translates prices $PA0_{g,r}$ by SUT category, to prices by COICOP category. Households pay taxes $\tau c_{c,r,t}$, of which VAT, excises and other product related taxes[16].

[16] These include, for example, registration duties on the purchase of real estate

Total prices on durable goods $PT_{dg,r}$ however consist of two components, the basic prices shown above, and the price of linked energy consumption:

$$PT_{dg,r} = PC_{dg,r} + \quad _{ener} a_{dg,ener} PC_{ener,r}$$

where $a_{dg,ener}$ is a parameter capturing the quantity of energy needed to typically operate a durable good.

c. Household Transport

In the current model, households use transport for three purposes: commuting, leisure and schooling. Total demand for leisure trips follows from utility maximisation, as outlined above, while their distribution across destinations is assumed to be exogenous. Schooling trips are fixed, while commuting trips depend on commuting, and thus on labour supply:

$XHT0_{r,rr,mot} = \omega_{LEIS_{r,rr}} \, QLeisTP_r$ if mot = 'LeisTP'

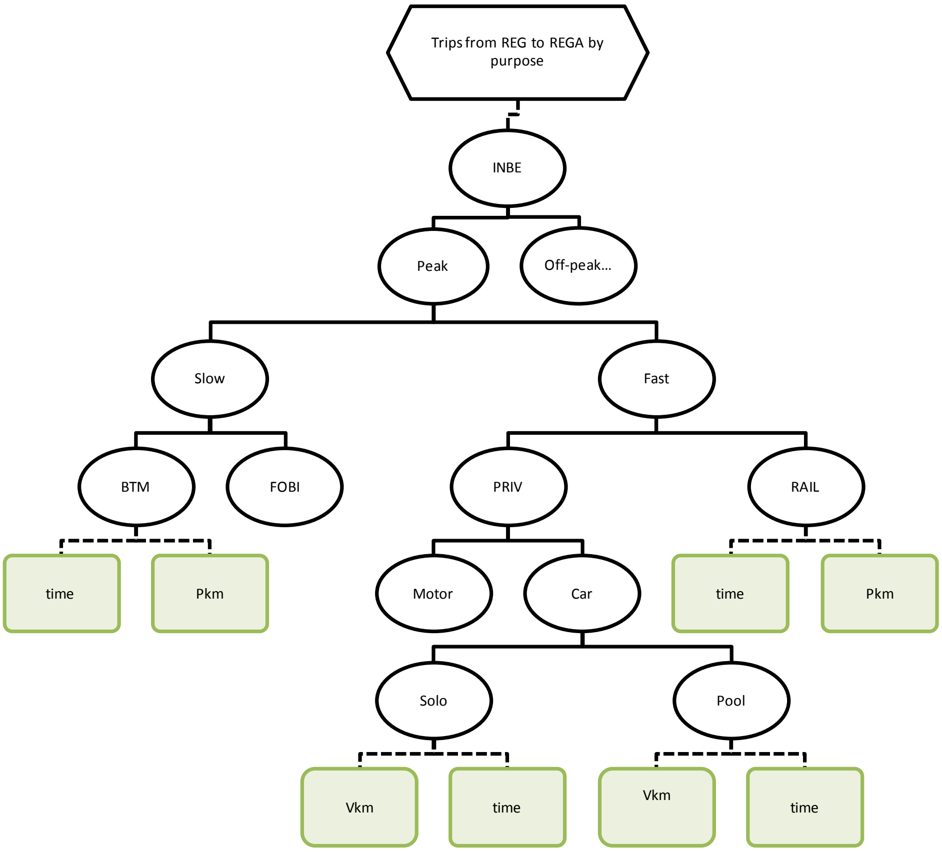
$XHT0_{r,rr,mot} = bxht0_{r,rr,mot}$ if mot = 'School'

$XHT0_{r,rr,mot} = bcc_{r,rr} \, COMM_{r,rr}$ if mot = 'work'

The household transport decisions are determined per trip purpose (commuting, school transport and leisure transport) and per production-attraction or origin-destination pair. Given total demand, the households are assumed to minimise their generalised transport costs subject to the household production technology for transport. The transport production function is a nested function as presented in Figure 22. The elements of the production function are passenger-km or vehicle-km and travel time:

- by the different modes: car solo, car pool, motorcycle, rail, bus/tram/metro/, on foot/by bicycle and air,
- per time period: peak and off-peak.

Figure 22: The production function for household transport (by household type, trip purpose and zone pair)



Lower level prices by mode are a composite of time and monetary costs. For each mode, we assume a unit time requirement (THT) and a unit requirement of transport inputs ($bmht$). For car transport, we assume fixed shares of cars, diesel and gasoline inputs[17]:

$$
\begin{aligned}
PHT6_{CAR_{r,rr,mot,pr,socc}} &= PHT7_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} \\
&+ PHT7_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} \\
&+ PHT7_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}}
\end{aligned}
$$

$$PHT5_{CAR_{r,rr,mot,pr,socc}} = PHT6_{CAR_{r,rr,mot,pr,socc}} + PCleis_r THT5_{CAR_{r,rr,mot,pr,socc}}$$

$$PHT4_{BTM_{r,rr,mot,pr}} = PMHT4_{BTM_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,prr}} + PCleis_r THT4_{BTM_{r,rr,mot,pr}}$$

$$PHT4_{MOTO_{r,rr,mot,pr}} = PMHT4_{MOTO_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,prr}} + PCleis_r THT4_{MOTO_{r,rr,mot,pr}}$$

$$PHT4_{RAIL_{r,rr,mot,pr}} = PMHT4_{RAIL_{r,rr,mot,pr}} bmht4_{RAIL_{r,rr,mot,prr}} + PCleis_r btht4_{RAIL_{r,rr,mot,pr}}$$

$$PHT4_{FOBI_{r,rr,mot,pr}} = PMHT4_{FOBI_{r,rr,mot,pr}} bmht4_{FOBI_{r,rr,mot,prr}} + PCleis_r btht4_{FOBI_{r,rr,mot,pr}}$$

Like upper level consumer prices, monetary prices in household transport are tax inclusive. As usual we distinguish between VAT, excises, subsidies and other product related taxes. Furthermore, in the case of household transport, the vehicle registration tax is modelled explicitly.

[17] An extension with endogenous choice between types of vehicles would be feasible in the future. The necessary data are readily available in PLANET.

Note that only in the cases of car, motorcycle and BTM transport unit time requirements are endogenous (see Section 4.1.6).

The average monetary costs and the average time per trip which result from these cost minimisation problems are an input in the utility maximisation problem of the households:

– the price of leisure transport is given by the average generalised cost of the trips for leisure purposes;
– the disposable extended income subtracts the time and monetary costs of commuting and school trips from the available budget.

4.1.2. The production sectors

The production side of the model considers 24 sectors (per region), 7 of which are transport sectors (sectors 18 to 25). An overview is given in Table XXX, which also presents the correspondence with the sectors of the Supply and Use Tables. The emphasis lies on industrial sectors, given their obvious link with freight transport, and transport service sectors.

Table XXX: The LIMOBEL production sectors

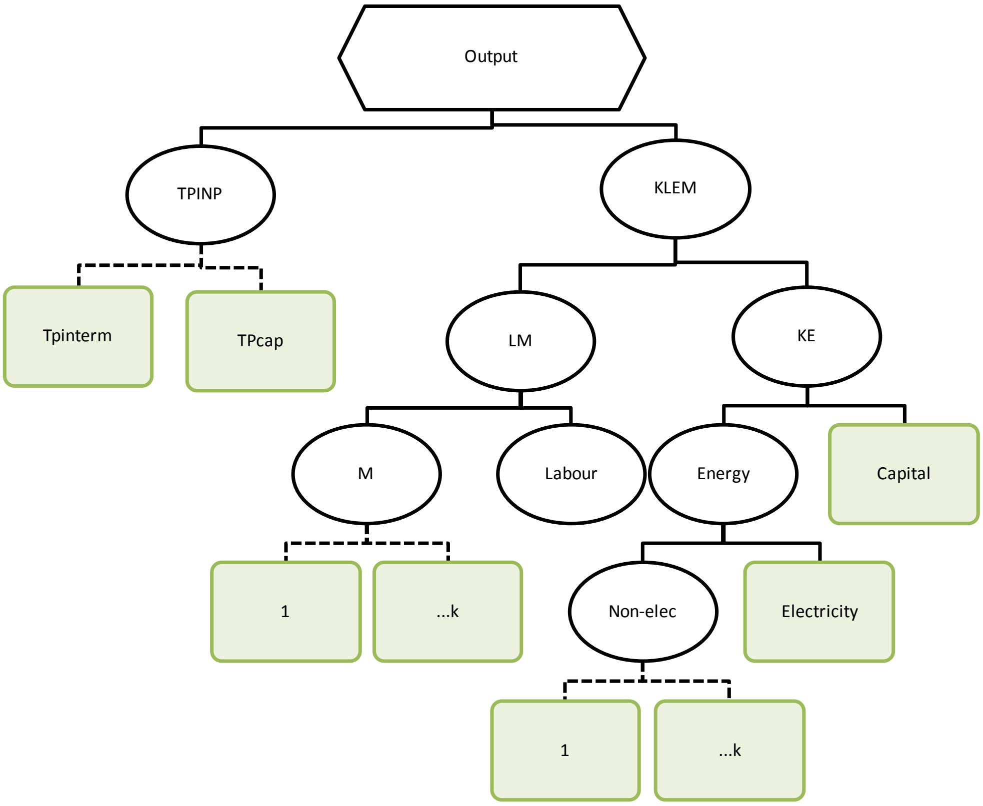
Sector no.	Description	Supply and Use Tables code
NON-TRANSPORT SECTORS		
1	Agriculture, forestry, fisheries	01,02,05
2	Cokes, Refined Oil, Nuclear Fuels	23
3	Ferrous and non - ferrous metals	27
4	Electricity	40
5	Raw Materials, building materials	14,26
6	Chemical Products, pharmaceutics	24
7	Other energy intensive industries (paper, plastics, metal products)	21,25,28
8	Electrical goods	30,31,32,33
9	Transport equipment	34,35
10	Machinery	29
11	Consumer goods	17,18,19,20,21,22,36,37
12	Food, drinks, tobacco	15,16
13	Construction	45
14	Water supply	41
15	Financial services	65,66,67
16	Market Services	50,51,52,55,63,64,70,71,72,73,74,85,91,92,93,95
17	Government Services	75,80,90
TRANSPORT SECTORS		
18	Rail	60A1
19	Road Freight	60C1
21	Bus/tram/metro	60B3
22	Other road Passenger Transport	60B1
23	Maritime transport	61A1
24	Inland navigation	61B1
25	Air transport	62A1

Table XXXI: The LIMOBEL products

Good no.	Description	Good no.	Description
NON-TRANSPORT GOODS		TRANSPORT GOODS	
1	Agricultural products	20	Road Freight
2	Solid Fuels	21	Maritime Transport
3	Liquid Fuels	22	Inland Navigation
4	Metals	23	Rail Freight
5	Raw Materials	24	Rail Goods
6	Chemical Products	25	Bus, Tram, Metro
7	Other Energy Products	26	Other Freight transport
8	Electrical Equipment	27	Other Passenger transport
9	Transport Equipment		
10	Other Equipment Goods		
11	Consumer Goods		
12	Food, Drinks and Tobacco		
13	Construction		
14	Water		
15	Electricity		
16	Gas		
17	Financial Services		
18	Other Market Services		
19	Government Services		

The firm, which operates in a perfectly competitive environment, minimises costs under the technological constraint which is represented by the nested CES function presented in Figure 23. Inputs are capital, labour, various energy inputs and other intermediates. The upper nest is only relevant for the transport sectors. At this level, producers choose transport inputs (TPINP), and the KLEM composite of labour, capital, energy and materials. The capital-labour-energy-intermediates (KLEM) composite is the result of the choice between labour and intermediates (LM) on the one hand and capital and energy (KE) on the other hand, according to a CES production function. At the next level the labour-intermediates composite is a CES function of the intermediates composite (M) and the labour composite (L). The input levels of the different intermediate inputs are determined according to a Leontief production function.

Figure 23: The general nested production technology for all sectors (by sector and region)



In equilibrium, firms do not earn any excess profits so that following restriction must hold:

$$PPtot_{sr}\,XVPtot_{sr}\,\left(1-\tau p_{prod_{sr}}+sp_{prod_{sr}}\right) = \sum_g PPnonelec_{gsr}\,XPnonelec_{gsr} + \sum_g PPint_{gsr}\,XPint_{gsr} + PPelec_{sr}XPelec_{sr} + PPlab_{sr}\,XPlab_{sr} + PPcap_{sr}XPcap_{sr} + \sum_g PPpint_{gsr}\,XPtpint_{gsr} + PPtpcap_{sr}\,XPtpcap_{sr}$$

This equation says that the value of production, net of taxes and subsidies on production, must be exhausted by the value of inputs. As before, input prices are tax – inclusive, with taxes on intermediate inputs falling mainly on energy products. The price of capital $PPcap_{sr}$ equals the rate of return PPK_{sr} net of corporate income taxes τp_t^K plus the cost of replacement investment $\delta_{sr}PINV$.

$$PPcap_{sr} = PPK_{sr}\left(1-\tau p_t^K\right) + \delta_{sr}PINV$$

No taxes are assigned to labour on firm level. Of course, this is not a heavy assumption, since due to the interplay of labour supply and demand income taxes will be borne by firms and households alike.

4.1.3. Freight and Trade

a. Freight transport

The trade sectors are auxiliary sectors that combine the commodities from the regions of origin with freight transport in order to deliver the commodities to the regions of destination. The number of trade sectors equals the number of zone pairs times the number of commodities. The zone pairs considered in the CGE model are presented in Table XXXII. The shaded zone pairs refer to trade between the Belgian regions, while the others concern international trade, with a distinction between trade relations with other the countries of the European Union and trade relations with the rest of the world.

Table XXXII: LIMOBEL: zone-pairs for trade sector

		Region of destination				
		Brussels	Flanders	Wallonia	EU	ROW
Region of origin	Brussels	X	X	X	X	X
	Flanders	X	X	X	X	X
	Wallonia	X	X	X	X	X
	EU	X	X	X		
	ROW	X	X	X		

Freight sectors minimise cost of ensuring a given level of trade, subject to the freight production technology which is shown in Figure 24. At the top level, commodities $XT1Comm_{r,rr,g}$ are combined with 'freight handling services' $XT1Freight_{r,rr,g}$ according to a Leontief fixed proportions function:

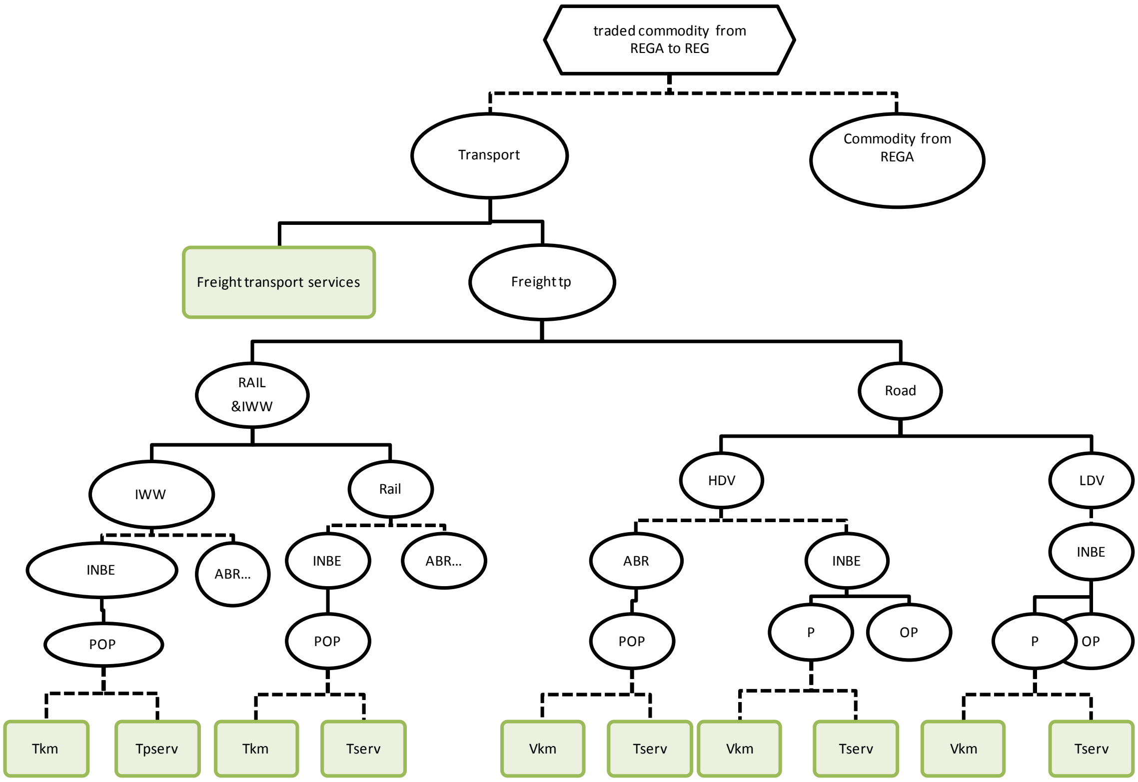
$$XT1Freight_{r,rr,g} = XT0Good_{r,rr,g}\alpha t^{1good}_{r,rr,g}$$
$$XT1Comm_{r,rr,g} = XT0Good_{r,rr,g}(1 - \alpha t^{1good}_{r,rr,g})$$

Prices of imported commodities are exogenous, if one assumes fixed exchange rates ER:

$PT1good_{r,rr,g} = p_{abr}ER$ if r = foreign region

'Freight' is itself a combination of 'services' (such as storage) and the transport itself. We allow for a (limited) degree of substitution between both, to account for changes in stock management efficiency due to changes in transport costs. Freight transport is a nested CES function of transport in different locations, by different modes (HDV, LDV, IWW,RAIL) and in different periods (Peak, Off-peak). The inputs at the lowest level include both physical inputs (tonne-km) as time related inputs. The last category of inputs depends on the speed of the different modes. For road transport in the peak and the off-peak period the speed can be made dependent on total traffic levels.

Figure 24: The production technology of the trade sectors (by zone pair and commodity)



As in household transport, lower level prices $PT6_{m,r,rr,g,l,pr}$ are a combination of monetary and time costs. Monetary costs are the unit requirement of transport services per vehicle-km $mt6_{m,r,rr,g,l,pr}$ while, in the current model, time costs are modelled as the unit requirement of the good 'market services' $TT6_{m,r,rr,g,l,pr}$:

$$PT6_{m,r,rr,g,l,pr} = PMT6_{m,r,rr,g,l,pr}\, mt6_{m,r,rr,g,l,pr} + PTT6_{m,r,rr,g,l,pr}\, TT6_{m,r,rr,g,l,pr}$$

$PTT6_{m,r,rr,g,l,pr}$ is the market price of the good 'market services' in the region of origin, while $PMT6_{m,r,rr,g,l,pr}$ is a composite of the prices of transport services from the three regions. We therefore assume that transport and service margins trade differently from other goods, which pass through the Armington trade structure which is presented below. The reason for this assumption, which we believe to be rather innocent, is ease of calibration and data limitations.

This choice of modelling the time inputs of freight is not at all final. For example, one could relate the use of time by freight to the wages of freight personnel. Also note the difference between the use of time by freight and households. In the case of household transport, a reduction in travel time increases the endowment of time, and therefore the total amount of resources in the economy. In the case of freight transport, time savings increase the efficiency in production (less resources needed per unit of output).

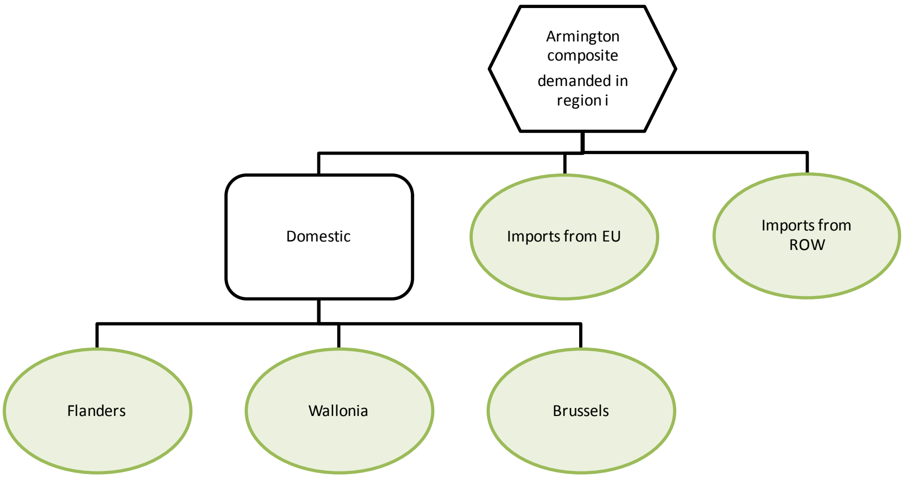
Note finally that only in the case of congested road transport, the unit time requirements are endogenous (see Section 4.1.6).

b. Trade

Trade between regions, except for freight margins, is modelled by the ubiquitous Armington trade structure, shown in Figure 25. As well known, Armington trade implies that consumers have preferences defined over the origin of goods. While as a theory of trade the Armington assumption has largely been rendered obsolete, it remains a popular assumption in applied large–scale models since it allows the modeller to reproduce real–life trade flows without having to resort to an explicit theory of trade.

In the current model, consumers have CES preferences over domestic goods, and imports from the EU and the Rest of the World (RoW). Domestic goods in turn are split into goods by region.

Figure 25: The trade structure in LIMOBEL (by domestic region)



Lower level prices and quantities correspond to the top level 'outputs' of the trade sectors. In the case of imports from RoW, we add import duties τm_g(an excise which is kept constant in real terms):

$$PA1Row_{rr,r,g} = PT0Good_{r,rr,g} + \tau m_g GDPDEF$$

On the export side, remaining faithful to the small open economy assumption, would imply an infinitely elastic demand for exports by the rest of the world. But this is inconsistent with the assumption that products are differentiated by country of origin. We therefore use an ad-hoc CES demand function to determine exports $XT0Comm_{r,rr,g}$:

$$XT0Comm_{r,rr,g} = bxt0Eu_{r,g} \alpha abr_{r,g} \frac{p_g^{abr} ER}{PT0_{r,g}}^{\sigma_g^{abr}} \quad \text{if rr = foreign region}$$

where $p_g^{abr}$is the exogenous price of foreign products, $PT0_{r,g}$the price of domestic goods, $\sigma_g^{abr}$is the elasticity of demand and $\alpha abr_{r,g}$ is a scaling parameter.

The small country assumption still holds, in the sense that a change in Belgian supply has no impact on the exogenous foreign price. It does however change the region's market share.

4.1.4. Government

The model captures as closely as possible the complex institutional arrangements in Belgium. We provide detailed accounts on revenue and expenditure for 5 different government entities as well as the limited role in taxation of the European Union.

The five governments that are considered are: the federal government (GFED), the three regional governments of Flanders (GFLA), Wallonia (GWAL) and Brussels (GBXL), and the French Community (GCFR). The Flemish community has been added to the Flemish regional government, the German community to the Walloon regional government, while the local governments (municipalities) have been added to the federal government. These choices were primarily made because of data issues.

a. Tax income

Thanks to the extensive database available at the FPB, we are able to distinguish between a wide variety of indirect taxes, levied on different components of demand. More precisely we distinguish between VAT, excises, other taxes on products, car registration taxes, import duties and taxes on agricultural products flowing directly to the European Union and subsidies. These indirect taxes can be distinguished as taxes on intermediate inputs, on final consumption, investment goods and government consumption.

Moreover, we have information on taxes and subsidies on production by sector, as well as labour and capital income taxes. Other taxes that have not been explicitly modelled, but that are needed to close the government constraint, are modelled as a 'Lump Sum' tax on households.

b. Government consumption

The basic constraint of the government is:

$$GOVBUDG_{gv} = TAXREV_{TOT_{gv}} + \underset{gvv}{\quad} GOVTRANSF_{gv,gvv} - \underset{gvv}{\quad} GOVTRANSF_{gvv,gv} - bgovtransfEU_{gv}GDPDEF - SAVG_{gv} - GTRF_{gv}$$

which says that expenditure, in the form of government consumption $GOVBUDG_{gv}$, transfers to households $GTRF_{gv}$, transfers paid to other governments $_{gvv} GOVTRANSF_{gv,gvv}$, transfers paid to the European Union $bgovtransfEU_{gv}$ and public saving $SAVG_{gv}$ must equal net tax revenues $TAXREV_{TOT_{gv}}$ and transfers received from other governments.

Transfers to households include all kinds of social transfers and pensions, as well as interest payments on government debt.

Government consumption $XG1_{gv,g}$ is allocated in a standard way across goods and regions. The government maximises a Cobb – Douglas utility function, keeping the shares of goods and regions $\alpha_{g,gv,r}^{gv}$ in its budget constant:

$$XG1_{gv,g} = \frac{GOVBUDG_{gv}\alpha_{g,gv,r}^{gv}}{PA0_{g,r}\ 1+\ {}_{t}\tau g_{g,r,t}}$$

c. Intergovernmental linkages

Transfers between governments follow as closely as possible the current institutional arrangements, at least for the relations from the federal government to the lower entities. Since we added the local governments to the federal government, the model exhibits a substantial flow from regional governments to this ‘federal government’ entity. These flows are kept constant in real terms.

The transfers from the federal government are modelled according to the Special Law on Finances. The mechanisms that are explicitly modelled are:

– the basic grant to the Regions: $BASICGEW_{gv}$
– the negative term: $NEGATIVE1_{gv}$
– the negative term from audiovisual taxes: $NEGATIVE2_{gv}$
– the solidarity grant: $SOLIDARITY_{gv}$
– the personal income tax (PIT) grant to the communities: $GRANTPIT_{gv}$
– the VAT grant to the communities: $GRANTVAT_{gv}$
– the additional Lambermont means: $LAMBERMONT_{gv}$

For the correct modelling of these flows, we also need to calculate the share of PIT revenue by community $TAXLOCGEM_{gv}$, and by region $TAXLOCGEW_{r}$.

4.1.5. Labour market

In this version of the model, we simply assume labour supply is distributed over different regions according to fixed shares $\alpha_{r,rr}^{COMM}$ yielding commuting flows.

$$\alpha_{r,rr}^{COMM} LABOUR_{r} = COMM_{r,rr}$$

By region, two measures of gross wages are constructed, from the viewpoint of households on the receiver’s side PW_{r}, and firms on the payer’s side $PPlab_{r}$:

$$\sum_{rr} COMM_{r,rr}\, PW_r = \sum_{rr} PPlab_r COMM_{rr,r}$$

Note that the assumption of a single regional wage implies perfect labour mobility across sectors.

4.1.6. Congestion

Road speed in each region and period (peak and off-peak) is a linear function of the road flow in the region and that period, expressed in passenger car units, in order to reflect the different contribution of cars, buses, vans and trucks to congestion. The road flow in a given region equals the sum of the road flow with origin and destination in the region itself and the part of the road flows between the region and other regions that takes place within that region.

The average speed for passenger and freight road flows between two regions depends on the speed in the regions that are crossed by these flows and on the share of km driven in each of these regions. This average speed determines the generalised costs of road passenger and freight transport that are used in Sections 4.1.1.c and 4.1.3.a.

4.1.7. Savings and Investment

The model's saving–investment closure is 'neo–classical', i.e. investment is determined by the amount of savings in the economy. Domestic saving $SAVDOM$ consists of savings by households, government savings and depreciation.

$$SAVDOM = \sum_{r} SAVH_r + \sum_{gv} SAVG_{gv} + \sum_{s,r} \delta_{s,r} PINV \cdot XPcap_{s,r}$$

To domestic savings we add the net inflow of capital from abroad to arrive at total investment:

$$INV = SAVDOM + NETINFLOW$$

Total investment demand is distributed across regions and sectors ($XI1_{r,g}$) by a Cobb – Douglas function according to fixed value shares $\alpha_{g,r}^{INV}$:

$$XI1_{r,g} = \frac{INV\alpha_{g,r}^{I}}{PA0_{g,r}\left(1+\sum_{t}\tau i_{g,r,t}\right)}$$

We also calculate regional ROR_r^{REG} and national rate of returns ROR:

$$ROR_r^{REG} = \frac{\sum_{s} PPcap_{s,r} XPcap_{s,r}}{\sum_{s} XPcap_{s,r}}$$

$$ROR = \frac{\sum_{s,r} PPcap_{s,r} XPcap_{s,r}}{\sum_{s,r} XPcap_{s,r}}$$

In this static model, the capital stock is fixed and immobile between sectors.

4.1.8. Other equilibrium conditions

The model is closed by a number of equilibrium conditions. The foreign equilibrium condition says that exports and the net inflow of capital needs to equal the value of imports, import duties, taxes levied by the EU and government transfers to EU.

$$\sum_{r,rr,g} XT0Good_{r,rr,g}\, PT0Good_{r,rr,g} + NETINFLOW$$
$$= \sum_{rr,r,g} XT1Comm_{rr,r,g} PT1Comm_{rr,r,g} + \sum_{gv} TAXREV_{TOT_{gv}}$$
$$+ \sum_{gc} bgovtransfEU_{gv} GDPDEF + \tau m_g XA1Row_{r,g} PA1Row_{r,g} GDPDEF$$

Foreign closure is ensured by varying the net inflow of capital, which implies fixed exchange rates. In practical applications of the model, we drop the foreign equilibrium condition and use it to check Walras' Law, which states that if in general equilibrium n-1 markets are in equilibrium, the n-th market will be in equilibrium as well.

4.2. Database and calibration

Remark: the CGE model is calibrated on the year 2003.

4.2.1. Regional supply and use tables

The Supply and Use tables (SUT) , describing in detail the composition of supply and demand of the regional economies, form the core of the Social Accounting Matrix (SAM) of the model. Due to a lack of data which would needed to construct regional SUT bottom-up, we made use of whatever data that could be found in the Regional Accounts to derive the SUT using top-down methods (Avonds, 2008). This section describes the procedure that has been followed, its assumptions, and the regional data that have been used.

a. The construction of regional Use Tables

A sketch of what a Use table looks like is provided in Table XXXIII.

Table XXXIII: General structure of a Use Table

	Sectors						**Final Demand**		
Goods	**I**						**III**		**Total Demand**
	II								
	Total Output								

The three major components are:

1. A goods x sectors matrix describing the components of intermediate demand by sector
2. A matrix describing the components of Value Added by sector. The components consist of gross wages (D1), depreciation (K1), gross operating surplus (B2N), taxes on production (D29) and production subsidies (D39)
3. A matrix giving the components of final demand, by good. The different components are household consumption, consumption of the non profit organisations, government consumption, collective government consumption, Investment, changes in inventories and exports.

Summing intermediate consumption and value added by sector gives total production, while summing across products gives total regional demand. Note that values in the Use table include taxes and transport/trade margins.

Given data for production, gross value added and gross wages, plus data on regional household disposable income and regional population, the Use table can be disaggregated. Where possible, the data have been constructed, first using the maximum disaggregation level available (256 SUT categories). Summation to 24 sectors and 27 goods has been done only at the end of the calculations to use the maximum amount of information available to us.

In order to reconstruct Part **I** of the Use table, total intermediate consumption is calculated using data on gross production and value added. By sector this total is split into different intermediate goods using a *same product mix* assumption: the composition of regional intermediate demand is assumed to consist of the same proportions of goods as in the national table. It is clear that such an assumption imposes an important degree of uniformity on the data. Applied to environmental policy, it effectively assumes that firms of the same sector have similar energy intensities – as a proportion of total intermediates – across Belgian regions.

The value added block **II** is regionalised as follows. Since D1 is given by the data, only K1, D29, D39 and B2N needed to be reconstructed. K1, D29 and D39 have been partitioned using regional total value added (VA) as a percentage of national VA as key. Gross operating surplus is calculated as a residual category (B2N = B1.g – D1- D29 – D39 – K1) Any differences in the share of the reward of labour will therefore translate into a lower profit rate, which leads to substantial variation in the share of the net return to capital across regions.

The components of final demand **III** are split as follows.

Total *household consumption* is split using regional income as a key, and distributed across goods using shares from the household budget survey. Total non profit consumption is split using regional population as a key and is distributed across goods using the familiar same product – mix assumption. Household consumption and non – profit consumption are aggregated, and are then translated into COICOP categories using a national table of correspondence.

In the case of *government consumption*, we dispose of estimates of consumption by good by different regional governments and of national, total consumption by good. Consumption by regional governments has been assigned to their respective region, while a part of the expenditures of the Flemish and French community governments takes place within the region of Brussels. The rest of national consumption, which can be attributed to the federal government and the local entities, is distributed across regions according to population.

Changes in *inventories* have been partitioned using regional value – added of their respective sector as a key. For those goods that are not produced in Belgium, and for which there is no VA available, regional intermediate use has been used as a key.

Calculation of *investment* by product is somewhat more involved. Regional investment by *sector* was available to us at the lowest level of disaggregation (SUT). Also available was a matrix breaking down *national* sectoral investment by sector into different products. This matrix has been used to calculate regional investment by *product* at the lowest level of disaggregation, and has only then been aggregated into coarser product categories.

Exports, to EU countries as well as ROW, have been partitioned using regional production by good (calculated by first constructing the domestic part of the supply tables). Exports for goods that are not produced in Belgium (re-exports of certain mining products) have been broken down according to regional intermediate use.

b. The construction of the regional Supply Tables

The general structure of a Supply table is presented in Table XXXIV. Block **I** breaks down the total output of each sector by good. This part of the table was easily reconstructed using the same market share assumption, which states that the same sectors in each region supply a same share of goods.

Block **II** gives total imports of each good. Imports have been calculated with the help of the national use tables of imports constructed at the FPB. For each cell in the (regional) use table, a share of imports has been calculated, which was then applied to the regional use tables described above. Imports could then be calculated by simply summing these regional Use tables of imports across sectors.

Table XXXIV: General structure of a Supply table

	Sectors					Imports	
Goods	I					**II**	**Total Supply**
	Total Output						

c. Linkages between regions

After constructing the SUT regional imbalances between demand and supply arise naturally. We therefore needed additional information to estimate the trade linkages between the different regions.

In general, information on interregional trade is very hard to come by. For trade in *goods*, we could resort to existing surveys on freight flows. One such dataset, based on the TRANS-TOOLS database, is used by FPB. This dataset gives freight flows between Belgian NUTS3 zones by mode and NST/R goods category. The simplest way to proceed with such data would be to calculate, by region, the share of each destination region in total regional exports. These shares could then be applied to domestic production by region from the Input-Output tables to obtain interregional trade flows.

For trade flows in *services* the lack of data is even more severe. As a last resort, we applied the shares for goods trade to the services sectors as well. However, we are currently implementing another approach which consists of *calibrating* service flows using the technique described by Treyz and Bumgardner (2001).

4.2.2. Government Accounts

In order to be able to model (exogenous) government behaviour, we would like to have data for each government in Belgium on the different tax and spending instruments in our model. Ideally, we would like to model the categories presented in Table XXXV:

Table XXXV: Overview of data on governments used in the CGE model

Revenues	Expenditure
Labour income taxes	Consumption (on 24 goods and services)
Capital income taxes	Transfers to other governments
Corporate income taxes	Transfers to households
Taxes on production	Transfers abroad
VAT	
Excise duties	Subsidies on products
Other consumption taxes[18]	Subsidies on production
Car registration taxes	

The regional government accounts have been provided by the department of public finance of the FPB.

The Input-Output team of the FPB has provided us with very detailed accounts of indirect taxes at the highest level of detail, for each cell in the Use table. We therefore have been able to discern indirect taxes by intermediate use, household consumption, imports, investment goods and even government purchases.

Table XXXVI and Table XXXVII give a complete overview of the government accounts as used in the model. Since the categories we use in the model do not add up to a realistic size of the government budget, we add a 'Lump Sum Tax' on households, to ensure that the deficits of the different governments correspond to those in the national accounts.

[18] 'Other taxes' include for example, registration duties on real estate sales.

Table XXXVI: Governments accounts – Receipts 2003 (MEUR)

	GFED	GFLA	GWAL	GBXL	GCFR	GEU
LABTAX	73535.7					
CAPTAX	9637.8					
VAT	18730.4					
ACC	6263.6	159.6	53	22		
TP	2458.2	1209.7	570.5	425.8		30
CAR		154.6	57.4	35.5		
SUB	-1620.4					-853.8
LST	5394.9	1994.2	758.1	525.1	1820.3	
Gtransfers	6475	15810	3521	1201	7409	

LABTAX: labour income taxes; CAPTAX: capital and corporate income taxes; ACC: excise duties; TP: taxes on production; CAR: car registration taxes; SUB: subsidies on products and production; LST: lump sum tax; Gtransfers: transfers from other governments

Source: BFP, own calculation

Table XXXVII: Governments accounts - Expenditures 2003 (MEUR)

	GFED	GFLA	GWAL	GBXL	GCFR	GEU
Consumption	40731.4	12740.1	2549.0	1436.3	5706.3	
HTransfers	41560.7	3254	485	148	1602	
Gtransfers	27233	3244	1689	1201	1720	
Ftransfers	2787.3					
Deficit	-403	30	-98	49	40	

Htransfers: transfers to households; Gtransfers: transfers to other governments; Ftransfers: Transfers abroad

Source: BFP, own calculation

The relevant transfers from federal government to the regions and communities are calculated from the overview of Algoed and Vanden Bossche (2009). The Numbers are presented in Table XXXVIII.

Table XXXVIII: Transfers from federal to regional governments 2003 (MEUR)

	GFLA	GWAL	GBXL	GCFR
Basic Grant	6507.6	2894.6	916.3	
Solidarity		747	101	
Negative Term-1	-1713.5	-698.4	-362.7	
Negative Term-2	-451.5	-217.7	-54.2	
PIT Grant	2038.2			1105.3
VAT Grant	5218.3			3951.1
Lambermont	621.6			413

Source: BFP, own calculation

4.2.3. Household Accounts

a. Data: income and expenditure categories

In Table XXXIX, we present the household income and expenditure accounts by category for the year 2003. Gross income categories and total consumption are taken from the national accounts. Taxes on labour income are calculated so as to match the localisation factors of personal income taxes taken from Algoed and Vanden Bossche (2009). Capital income taxes are calculated from a national flat tax assumption.

Table XXXIX: Household account by category 2003 (MEUR)

	Brussels	Flanders	Wallonia
Expenditure			
Consumption	13869.3	87721.4	42443.9
Capital income tax	162	1033.7	430.5
Labour income tax	6699.2	46071.0	20756.6
‘Lump Sum’ Tax	1306.3	5136.1	4050.2
Income			
Gross Labour income	9683	64217.7	29377.6
Gross Capital income	5627.5	35907.7	14956.3
Transfers	971.7	3397.3	2993.3
Savings	1466	11137.4	3845.8

Source: BFP, own calculation

Expenditures by categories are calculated by applying regional consumption shares (of SUT categories) taken from the household budget survey. Translation into COICOP categories is done through a national correspondence matrix, yielding the results presented in Table XL.

Table XL: Households – expenditures by category (2003)(MEUR)

	Brussels	Flanders	Wallonia
Total Consumption	13869.3	87721.4	42443.9
Gas	225.2	1132.1	489.2
Electricity	218.1	1751.5	968.3
Other energy	85.3	756.3	511.9
Health	620.7	3800.6	1883.3
Textiles	755.2	5025.7	2273.7
Food	2235.4	14967.3	7821.6
Household equipment	874.8	5280.9	2686.9
Services	4923.1	30241.2	14573.5
Heating equipment	79.5	739.8	320.5
Other durables	2600	15939.6	7140.5
BTM	245.4	173.3	141.2
Rail	66.1	319.9	126.7
Diesel	86.6	739.5	496.7
Gasoline	151	1289.5	866.2
Foot and Bicycle	22.1	175.0	67.5
Car purchase	647.9	5128.1	1976.5
Motorcycles	33.0	261.1	100.6

Source: Supply and Use Table, Household budget survey, BFP, own calculation.

b. Household transport

The PLANET database contains detailed information on commuting trips and school journeys by mode of transport and time period, by origin and destination on NUTS-3 level. These PLANET data are taken from the Socio–Economic Survey of 2001. For other trip purposes (termed ‘leisure trips’ in the CGE model), we only have an idea of total trips. Origin–Destination data for these other purposes are lacking. We therefore had to assume that leisure trips are distributed according to the distribution of *total* car vehicle-km in NODUS. Table XLI presents the total number of passenger-km made by regional households per mode, time period and trip purpose.

The extensive PLANET database contains detailed information on average trip duration for work en school trips, by period, mode and origin-destination pair. Again, such detailed information for other purposes is not available so we had to make assumptions: in particular time costs for other purposes are assumed to follow the same pattern as school trips.

Table XLI: Passenger-km per regional household (mio. passenger-km, 2003)

	Brussels		Flanders		Wallonia	
	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak
Commuting						
Bus/tram/metro	137.7	426.8	437.8	1112.9	122.5	331.7
Rail	76.1	893.8	110.9	1028.3	80.1	566.5
Car – solo	664.2	1871.5	3614.9	9458.9	1966.9	5038.6
Car – Pool	66.0	261.4	468.1	938.2	285.5	686.1
Moto	6.8	22.5	127.5	206.3	43.2	63.6
Foot/bicycle	8.2	17.2	140.8	290.2	5.9	10.8
School						
Bus/tram/metro	31.2	297.1	124.5	1083.3	55.4	526.4
Rail	8.2	78.7	36.1	348.3	27.1	268.3
Car – solo	11.2	46.5	54.8	225.6	40.1	165.5
Car – Pool	49.1	234.1	330.3	1390.5	338.5	1481.7
Moto	0.4	3.1	8.5	69.0	1.9	15.6
Foot/bicycle	7.0	19.7	76.5	299.9	3.6	10.4
Other						
Bus/tram/metro	300.3	73.0	1196.9	266.2	532.8	129.4
Rail	333.3	59.2	1461.5	262.1	1095.2	201.9
Car – solo	3766.6	297.5	18383.1	1443.5	13450.4	1058.9
Car – Pool	2070.9	203.4	13943.1	1208.0	14286.0	1287.2
Moto	39.2	3.3	856.1	72.2	194.7	16.3
Foot/bicycle	64.2	10.0	704.8	109.8	32.9	5.1

Source: Desmet et al. (2008)

c. Calibration

Following Boeters and van Leeuwen (2009), we calibrate the wage and income elasticity of labour supply by appropriately choosing the household time endowment T and the top nest elasticity of substitution σc_r^0. The target income elasticity is -0.1, while the desired wage elasticity is 0.2.

Table XLII gives the calibrated own price and income elasticity of goods other than transportation. These elasticities are held as closely as possible to (long run) HERMES estimates. Of course, in the case of own price elasticities, it is not possible to fully determine all elasticities, since the current utility function allows for a limited number of degrees of freedom.

The elasticities of household transport (Table XLIII) are kept as closely as possible to those used in PLANET.

Table XLII: Calibrated own price and income elasticity of goods

	Brussels	Flanders	Wallonia
Own Price Elasticity			
Electricity	-0.672	-0.684	-0.653
Gasoline	-0.672	-0.686	-0.655
Other Energy	-0.675	-0.687	-0.655
Heating Appliances	-0.675	-0.687	-0.656
Other Energy Goods	-0.624	-0.631	-0.624
Health	-1.231	-0.854	-1.172
Textiles	-0.825	-0.575	-0.786
Food	-0.920	-0.687	-0.887
Household Equipment	-0.765	-0.533	-0.729
Electricity	-0.672	-0.684	-0.653
Income Elasticity			
Electricity	0. 710	0. 710	0. 710
Gasoline	0. 710	0. 710	0. 710
Other Energy	0. 710	0. 710	0. 710
Heating Appliances	0. 710	0. 710	0. 710
Other Energy Goods	0. 710	0. 710	0. 710
Health	1. 170	1. 170	1. 170
Textiles	0. 770	0. 770	0. 770
Food	0. 850	0. 850	0. 850
Household Equipment	0. 710	0. 710	0.710
Services	1. 170	1. 170	1. 170

Source: CGE – LIMOBEL

Table XLIII: Calibrated elasticities of household transport

Mode	Purpose	Peak	Off-peak
BTM	Commuting & school	-0.21	-0.34
	Other	-0.44	-0.63
Rail	Commuting & school	-0.43	-0.52
	Other	-1.16	-1.51
Car Solo	Commuting	-0.11	-0.13
	School	-0.22	-0.20
	Other	-0.48	-0.34
Motorcycle	Commuting	-0.23	-0.22
	School	-0.12	-0.13
	Other	-0.26	-0.29
Car Pool	Commuting	-0.45	-0.41
	School	-0.06	-0.06
	Other	-0.30	-0.34

Source: CGE - LIMOBEL

4.2.4. Freight Transport

a. Data

From the PLANET database, we had the number of tonne-km driven in 2003 by zone pair and NST/R good, as well estimates of the unit time and monetary costs for different modes. From these data, and by making assumption on the correspondence between NST/R categories and SUT goods, we were able to calculate the transport costs that are associated with transport between all Belgian regions and abroad (at least for the modes that are currently under consideration).

In a next step of the construction of the data, the social accounting matrix must be adapted to suit the calculation of these new transport and freight margins. More precisely, we adapt our original Use table, whose prices only include service margins and taxes, to purchaser's prices containing transport margins as well.

Technically, this is done as follows:

By region, the total amount of transport costs for goods *towards* a region, and the total transport costs of exports *from* a region are calculated.

We divide that total amount across demand sources (sectors, households, government, investment, export) according to transport demand by source.

That amount is subtracted from transport expenditure, and added to the purchase costs of goods in such a way that total demand by source is respected.

Note that for time costs of transport such calculations are not needed since they can be readily included in the service margins that are already calculated.

b. Calibration

For the calibration of the trade production function, we make use of the elasticities provided in the PLANET report. They are summarised in Table XLIV:

Table XLIV: Elasticities of substitution for freight transport

Parameter		
$\sigma t_{r,rr,g}^{1Freight}$	All	0.2
$\sigma t_{r,rr,g}^{2Transport}$	if good = 1,11	1.2
	rest	2
$\sigma t_{r,rr,g}^{3Railiww}$	All	2
$\sigma t_{r,rr,g}^{3Road}$	if good = 2a,4,5	0.2
	if good = 2b,3	0.9
	if good = 1	1.1
	rest	2
$\sigma t_{r,rr,g}^{4Iww}$		1.1

Parameter			
$\sigma t^{4Rail}_{r,rr,g}$			1.1
$\sigma t^{4Road}_{m,r,rr,g}$			1.1
$\sigma t^{5Road}_{m,r,rr,g,l}$	if l = 'abr'	if good = 6-10	1.2
		if good = 1,11,3	1.4
		if good = 2a,2b,4,5	2.4
	if l = 'inbe'	if good = 1,2,6-10	0.7
		if good = 2a,2b,4,5	1.2
		if good = 11	1.7

Source: Desmet et al. (2008)

4.2.5. The road network and congestion

In the model all trips, both in the case of freight and passenger transport, are modelled by origin and destination pair while the congestion functions are defined regionally.

The parameters $\alpha^{TRIPS}_{r,rr,rrr}$, determining which part of the origin-destination flows takes place within a region, are taken from the NODUS database (no distributions by period were available). These yield road flows per region and per period, that are then used to calibrate the linear speed-flow relationships. In the current model, we assume peak and off-peak speed to be the same in every Belgian region. More precisely, we assume that average nationwide speeds are 47 km/h at peak periods, and 77 km/h in the off-peak.

4.2.6. Other calibration issues

The elasticities of substitution for the Armington trade function are 1.5 for the top nest, and 3 for the lower nest. Except for the fact that we deliberately choose higher substitution possibilities domestically than internationally, these values are of course rather arbitrary.

For the calibration of the production function, we choose parameters to mimic as closely as possible the own price elasticities of HERMES for labour, capital and energy. Note that due to limited degrees of freedom, we cannot choose the elasticity of the materials bundle.

For the transport sectors, we choose a rather low value for the upper nest elasticity of 0.2 for all sectors. For the elasticity of the energy nest, $\sigma p^{4a}_{s,r}$, we have picked the value of 1.1. The other elasticities of substitution are chosen to yield values for the (long – term) own price elasticities of capital, energy and labour close to those of HERMES, which are listed in Table XLV.

Table XLV: Own price elasticities of capital, energy and labour

Sector	Labour	Capital	Energy
Agriculture, forestry, fisheries	-0.71	-0.28	-0.63
Cokes, Refined Oil, Nuclear Fuels	-0.39	-0.77	-0.59
Ferrous and non - ferrous metals	-0.42	-0.30	-0.63
Electricity	-0.39	-0.77	-0.59
Raw Materials, building materials	-0.42	-0.30	-0.63
Chemical Products, pharmaceutics	-0.42	-0.30	-0.63
Other energy intensive industries (paper, plastics, metal products)	-0.42	-0.30	-0.63
Electrical goods	-0.87	-0.59	-0.64
Transport equipment	-0.87	-0.59	-0.64
Machinery	-0.87	-0.59	-0.64
Consumer goods	-0.71	-0.28	-0.63
Food, drinks, tobacco	-0.71	-0.28	-0.63
Construction	-0.80	-0.63	-0.99
Water supply	-0.39	-0.77	-0.63
Financial services	-0.81	-0.61	-1.40
Market Services	-0.86	-0.25	-1.75
Government Services	-0.86	-0.25	-1.75
Rail	-0.85	-0.35	-0.95
Road Freight	-0.64	-0.84	-0.77
Other road Passenger Transport	-0.64	-0.84	-0.77
Bus/tram/metro	-0.64	-0.84	-0.77
Maritime transport	-0.85	-0.35	-0.95
Inland navigation	-0.85	-0.35	-0.95
Air transport	-0.85	-0.35	-0.95

Source: HERMES

4.3. Encountered difficulties

4.3.1. Dynamics

In some CGE models, simple dynamics are introduced by assuming a ‘steady state’ growth path in which all variables grow at the same rate. Such a growth path is sometimes imposed in a rather ad-hoc way, without much reference to an underlying growth model. Dynamic simulations then simply consist of calculating variations from such a benchmark path.

For a transport model that seeks to shed light on issues as optimal congestion taxes, this not a satisfactory approach. For example, one can imagine that constant growth of traffic flows would yield falling speed levels over time, making it very hard to design a steady–state unless one tinkers somehow with the congestion function. Of course, doing so would yield rather uninteresting results.

Constructing a meaningful steady state scenario would almost surely imply simplifying the model to a large extent, which we were not prepared to do at this stage. Right now we have a model that is rich in many features and dimensions, and which is capable to incorporate a wide range of effects. Given the partial nature of many theoretical and applied papers in optimal transport taxation, this may be considered as an interesting exercise on its own.

The price we pay is that results from this model are necessary incomplete in another way. As will be shown below, suppressing the time dimension is important in judging the optimality of taxation, although even then it may be interesting to show how omitting the constant-returns-to-scale assumption in many applied papers affects results and opens the way to some interesting inter-temporal trade-offs.

4.3.2. Labour market

Although we experimented with different labour market setups, such as uncompetitive wage setting and labour supply along two margins, in the present version of the model we chose to stick to competitive labour markets. The assumption of perfect competition seems to be a good baseline, while we encountered some substantial difficulties in modelling the intensive margin within an interregional setting.

4.4. Added value of a static CGE model

In the framework of the LIMOBEL project, a static set-up of a regional CGE model for Belgium and its three regions has been constructed. The CGE approach allows modelling the two-way interactions between transport and the economy in general.

This interaction is not modelled in the PLANET model. Both models are thus complementary. Up to now, the PLANET model is more suitable to analyse the long run impact of transport policies on transport itself, while the CGE model allows analysing the impact of policies (general policies or focused on transport) on the economy in general and on the transport sector. To be more precise, on the one hand, the CGE models endogenously the implications of economic developments on transport use. Given the focus on transport issues, passenger and freight transport are represented in a more detailed way than in similar models. Transport generation and the interregional trip distribution are determined endogenously, both for passenger and freight transport. The freight flows between the three regions are linked to the trade flows, while the number and distribution of commuting flows follow from the labour supply. On the other hand the model can be used to determine the indirect impacts of changes in the transport sector on the economic system and the location of activities in the three Belgian regions. This way, one can calculate the full welfare impacts of policy changes, taking into account the impacts on all economic agents and not only on the transport sector. By incorporating different household groups, the equity impacts of policies can also be analysed.

An additional advantage of the CGE model (w.r.t. the PLANET model) is to improve the traditional cost- benefit analysis by incorporating indirect effects. As example, if we introduce a road tax, it is possible – with the CGE model – to analyse the direct and indirect effects on the labour supply, namely the direct loss due to tax itself and the indirect gains due to tax recycling and the lower commuting time.

4.5. Simulations

This section presents the first results of the CGE model. We have chosen an simple kilometre charge on household car transport as an illustration of how the model works. These results should, however, not be considered as final policy recommendations since more work needs to be done in validating both the database as well as the theoretical structure of the model. The policy is therefore kept as general as possible, without reference to concrete proposals such as those in Section 3.4.3, let alone estimates of marginal external costs – which are a natural benchmark to judge the optimality of transport taxes in a first best setting.

4.5.1. Kilometre charge on cars

This section presents the results of a kilometre charge on car passenger transport only. The charge is modelled as an ad-valorem tax on road transport so that the composite monetary price of car transport becomes:

$$PHT6_{CAR_{r,rr,mot,pr,socc}} = PHT7_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} + PHT7_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} + PHT7_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}} * (1 + roadtax_{pr})$$

The initial values of the tax amount to 0.01 for off-peak travel, and 0.04 for peak travel. There is no differentiation by purpose and zone-pair. The differentiation by time period is arbitrary. Accompanying this tax reform, we suppress the regional vehicle registration taxes which, in the model, act as a kilometre charge that is undifferentiated with respect to time.

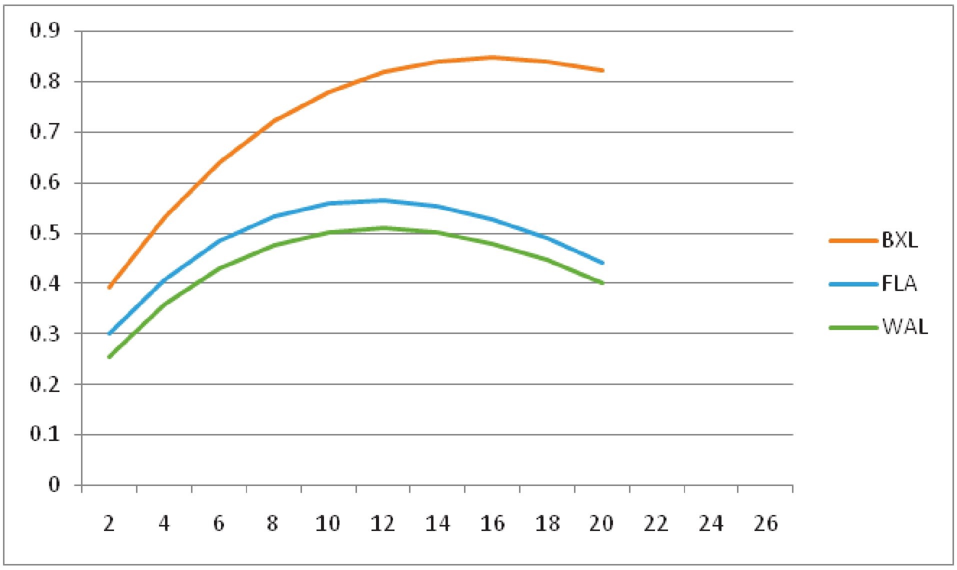
The proceeds of this new charge are entirely recycled back to households, in the form of an earned income tax credit $REBATE_r$. More precisely, the price of leisure will become:

$$PCleis_r = \frac{(PW_r \; 1- \; {}_t\tau y_t^{LAB} - \; {}_t\tau y_t^{SS} \; - CC_{TOT_r} + REBATE_r)}{(1+CT_{TOT_r})}$$

The tax reform will affect government budgets through other channels, so that some way of government closure is necessary. For the federal government, we assume that the budget is balanced by varying the social security tax rate. Regional governments have limited tax instruments at their disposal, so we assume they vary the level of government consumption.

Before the presentation of the impact of the alternative scenario on transport and on economy in general, Figure 26 presents the gain in indirect utility according to tax level (for example, the level of value at '12' gives results for the gain in utility for 12 times the benchmark tax level). For an in-depth discussion of the impact of a road kilometre charge, we focus on results for a tax level of about 12 times the benchmark tax level.

Figure 26: Gain in indirect utility according to tax level
(% points compared to the benchmark tax level)



Source: CGE – LIMOBEL

The three following tables present the impact of the kilometre charge on car, including recycling of those tax revenues, on the economy (Table XLVI), on road transport (Table XLVII) and on tax revenues of the governments (Table XLVIII). The results are presented in percentage with respect to the reference scenario (REF scenario). The REF scenario is the CGE model calibrated on the year 2003 (and thus without kilometre charge).

Table XLVI gives some general economic effects. As expected, the reform has positive effects on labour supply and employment. Although wages fall in equilibrium, the price of leisure rises markedly due to the combined effects of the tax decrease (through tax recycling) and gains in commuting times, which by far outweigh the drop in wages and the rise in monetary commuting costs. We note the increase in the rate of return, which is an obvious mirror effect to the drop in wages. The discussion here below points out the importance of the behaviour of the price of capital for interpreting the results.

Table XLVI: Effects on a kilometre charge on car on the economy
(difference in % with respect to the REF scenario)

	Brussels	Flanders	Wallonia
GDP	0.25	0.34	0.39
Disposable income	2.11	1.69	1.78
Employment	0.73	0.41	0.54
Wage Rate	-0.15	-0.15	-0.22
Price of leisure	1.10	1.25	1.48
Commuting time	-12.24	-12.55	-14.21
Commuting costs	24.32	31.10	32.18
Rate of Return	1.42	1.38	1.68

Source: CGE - LIMOBEL

Table XLVII gives some result from the transportation side of the model. Total road traffic flows drop by some 16% in Flanders to 13.4% in Brussels in peak periods, while falling to a lesser extent in off–peak hours (round 1%). Part of the more substantial drop in household flows is offset by increased road usage by freight transport in the peak period. The larger drops of car vehicle-km driven by Walloon households, and the more than average fall in leisure trips in Wallonia are striking.

The new tax yields a revenue of about 2081 MEUR, of which some 170, 1319 and 592 MEUR are levied on households from Brussels, Flanders and Wallonia, respectively. It is insightful to explain in larger details the changes in government tax revenues and other expenses. One would expect other tax revenues to rise substantially as a result of a tax reform that increases incomes and production, allowing the federal government to cut labour income taxes even further. However, we show that such effects are limited by the presence of other distortions.

Table XLVII: Effects of a kilometre charge on household transport on road transport
(difference in % with respect to the REF scenario)

		Brussels	Flanders	Wallonia
Road flow households	Peak	-15.14	-22.46	-18.65
	Off – Peak	-9.32	-9.12	-14.49
Road flow freight	Peak	7.31	8.39	7.76
	Off – Peak	-0.85	-1.17	-0.54
Road flow total	Peak	-13.41	-15.86	-14.72
	Off – Peak	-8.63	-7.20	-12.46
Car vehicle-km	Peak	-22.06	-22.93	-17.46
	Off – Peak	-2.00	-10.00	-15.68
Speed	Peak	18.13	21.25	22.40
	Off - Peak	2.74	2.24	5.14
Commuting trips		1.18	0.39	0.53
Leisure trips		-10.58	-21.77	-22.43

Source: CGE-LIMOBEL

Table XLVIII presents the changes in tax revenues for the different governments.

Table XLVIII: Effects on a kilometre charge on household transport on tax revenues from the governments
(difference in % with respect to the REF scenario)

	GFED	GFLA	GWAL	GBXL
VAT	-0.28			
Other product related taxes	1.48	0.45	0.45	0.45
Excises	-1.31	1.50	1.63	1.25
Subsidies	-1.69			
Taxes on labour income	0.55			
Capital income taxes	1.39			
Car taxes		-67.99	-68.05	-67.70
Total tax Revenue	0.43	-5.75	-6.32	-4.05
Total government budget	n/a	-0.07	-0.60	-1.22

Source: CGE - LIMOBEL

There are few surprises on the accounts of the regional governments. They lose substantial tax revenues, although some of these losses are mitigated by increased transfers from the federal government. The federal government gains some revenues from increased direct income taxation, but actually loses revenues through excises and (to a small extent) VAT payments. Of course, these losses are related to the large drop in km driven by car, and the corresponding fuel excises and lower VAT due to lower car sales. Correspondingly, the reduction in the social security tax rate by the federal government is only marginal.

Before we present some sensitivity analyses, one remark is in order. Remember that the current model is a static one, with fixed capital stocks (immobile across sectors). Unlike the simplified models that are used in theoretical research, our model does not display constant returns to scale, so that wage rates are not fixed and not every extra unit of labour supply will find itself employed. Decreasing returns will therefore imply that the efficiency gains of the tax reform will not fully materialise within one time period.

If the change in the rate of return is a good proxy for future wage growth, then tax levels that are sub-optimal in one period may yield larger gains in the future (see Table XLIX).

Table XLIX: Rate of return
(difference in % with respect to the REF scenario)

Tax level	Brussels	Flanders	Wallonia
12	1.42	1.38	1.68
14	1.59	1.52	1.86
16	1.74	1.64	2.02

Source: CGE - LIMOBEL

From the literature, we know how important existing taxes in all markets are in determining the welfare effects of additional transportation taxes. A general equilibrium model such as ours is of course well positioned to shed light on such second best issues.

For example, higher substitution between car and rail transport may worsen the welfare outcomes of a road tax, since car transport is already taxed rather heavily, while passenger rail transport is subsidised. As households substitute away from cars to public transportation, they cause a bigger revenue shortfall for the federal government, which would have to be compensated for elsewhere.

As a sensitivity analysis, Table L and Table LI present the welfare and public finance effects of the road tax for an elasticity of substitution $\sigma ht^{3a}_{r,rr,mot,pr}$ between private and rail transport that is 50% larger than the one used in the baseline scenario.

Table L: Sensitivity analysis w.r.t elasticity of substitution between private and rail transport: effect on utility

(difference in % with respect to the REF scenario)

	Brussels	Flanders	Wallonia
Utility (baseline σ)	0.82	0.57	0.43
Utility (50% higher σ)	0.73	0.48	0.42

Source: CGE - LIMOBEL

Table LI: Sensitivity analysis w.r.t elasticity of substitution between private and rail household transport: effect on federal finances
(difference in % with respect to the REF scenario)

	VAT	**Excises**	**Subsidies**	**Total**
Revenue (baseline σ)	-0.28	-1.31	-1.69	0.43
Revenue (higher σ)	-0.36	-1.41	4.66	-0.42

Source: CGE - LIMOBEL

As expected, the welfare gain is significantly lower with a larger elasticity of substitution than in the base case, while losses in tax revenue of the federal government are significant. The increase in subsidies, due to a higher demand for rail transport, has a negative effect on the public budget, prompting the federal government to actually raise social security contributions, if only by a small margin.

Another candidate for sensitivity analysis is the elasticity of substitution between peak and off-peak travel for *freight* transport, $\sigma t^{5Road}_{m,r,rr,g,l}$. The reason is that the more taxing car transport implies displacing cars for trucks, the less congestion is solved. Table LII illustrates this effect, by giving the changes in utility, speed and road flows for the base case and a $\sigma t^{5Road}_{m,r,rr,g,l}$ that is again 50% larger. An increase by 50% of these substitution elasticities for freight transport leads to smaller increase in speed, compared to the baseline substitution elasticities. This impact is explained by the higher substitution of freight transport from off-peak period to peak-period. Consequently, the higher the substitution elasticities between period for road freight transport, the lower is the beneficial effect of a kilometre tax on congestion.

Table LII: Sensitivity analysis w.r.t elasticity of substitution peak and off-peak for freight : effect on utility, speed, and road flow
(difference in % with respect to the REF scenario)

		Brussels	Flanders	Wallonia
Baseline σ				
Utility		0.82	0.56	0.51
Speed	Peak	18.13	21.25	22.40
	Off-peak	2.74	2.24	5.14
Road flow households	Peak	-15.14	-22.46	-18.65
	Off-peak	-9.32	-9.12	-14.49
Road flow freight	Peak	7.31	8.39	7.76
	Off-peak	-0.85	-1.17	-0.54
50% Higher σ				
Utility		0.81	0.55	0.49
Speed	Peak	17.96	20.57	21.91
	Off-peak	2.76	2.33	5.20
Road flow households	Peak	-15.24	-22.60	-18.74
	Off-peak	-9.28	-9.06	-14.47
Road flow freight	Peak	9.94	11.36	10.39
	Off-peak	-2.11	-2.60	-1.81

Source: CGE-LIMOBEL

5. POLICY SUPPORT

5.1. Lessons learned from the historical analysis

For the historic years the E-Motion model finds that CO_2 emissions by the Belgian *car fleet* fell by 2.6% in the period 2000-2008, with the largest reduction taking place between 2007 and 2008. The evolution is the result of the increase in the total number of cars (leading to an increase of CO_2 emissions by 9.4%), the switch from gasoline to diesel cars and the changes in the annual mileage per car (-7.1%), the increasing share of smaller cars (-1.7%) and the improvement in fuel efficiency over time (-3.3%).

The fuel efficiency of *new* passenger cars in Belgium has improved between 2002 and 2009, both for diesel and petrol cars. The down-sizing of the engines is responsible for part of this decrease. The reduction is however more pronounced for petrol than for diesel cars. Between 2004 and 2007 there was only a small reduction in the fuel consumption of diesel cars. This is due to the rising sales figures of diesel cars with large cylinder capacities. The stronger decrease after 2007 can be explained by the increase in sales figures of small diesel cars. Furthermore, there is an increase in sales of green cars. These include hybrid vehicles and low CO_2-emitting petrol and diesel fuelled vehicles (by e.g. improved aerodynamics, start-stop systems, lower rolling resistance). The evolution was encouraged by several policy measures: the direct discount for new energy efficient diesel cars and the introduction in 2007 of the CO_2 emissions as a determinant for the tax deductibility of company cars. Also European policy towards low CO_2-emitting cars pulls in the right directions.

CO_2 emissions can directly be deduced from the petrol and diesel consumption figures. So, the *average CO_2 emissions of new cars* also drop between 2002 and 2009. In 2009 the average CO_2 emission from new passenger cars in Belgium was 144.3 g/km. The European directive EC/443/2009 enforces an average for the whole of the EU of 130 gCO_2/km by 2015. The evolution of CO_2 emissions from new cars shows it will possibly not be reached by 2015 in Belgium. But, if CO_2 emissions from new cars continue to follow the evolution of the last three years (2007-2009), it would be easy to meet the objective for Belgium. At this stage it is however not yet clear whether the recent evolutions are structural or due to the economic crisis.

5.2. Lessons learned from the LIMOBEL reference scenario

The new version of the PLANET model was used in combination with the environmental impact assessment model and the NODUS model to update the reference scenario for long-term transport and mobility development in Belgium.

The reference scenario projects a further growth between 2005 and 2030 of passenger and freight transport by respectively 31% and 60%. In combination with the continuing dominance of the road modes, this would further deteriorate traffic conditions in Belgium, as reflected in a fall in average speed by 31% in the peak period and 17% in the off-peak period. As a result, the currently observed discrepancy between taxes and marginal external costs is projected to worsen over time. As concerns the evolution of the (direct) emissions related to the transport activity the implementation of environmental policies in the reference scenario will be successful in reducing emissions of the traditional air pollutants (CO, $PM_{2.5}$, NMVOC, NO_x and SO_2), even when taking into account the growth in transport. Greenhouse gas (GHG) emissions will increase, however, by 3% between 2005 and 2030. The consumption of fuel for the transport activity increases by 14.4% in the same period.

The LIMOBEL project performed detailed calculations to update the estimates of the marginal external costs per tonne of $PM_{2.5}$ and NO_x emissions. For the other pollutants a literature review was made. The LIMOBEL calculations for future years take into account the change in the background concentrations and the demographic projections. For the $PM_{2.5}$ emissions the marginal external costs are positive and increasing over time. The increase can be explained almost completely by the demographic evolution. In the case of the NO_x emissions, we find a marginal external benefit rather than a cost in 2007 because higher NO_x emissions lead to a reduction of the concentrations of sulphate aerosols and aerosols. In 2020 and 2030 this positive effect is no longer large enough to compensate for the damages caused by the higher concentrations of nitrate aerosols. In those years the NO_x emissions are therefore associated with a marginal external cost.

When we combine these estimates with the projected evolution of the emissions of the reference scenario, we can calculate the total environmental costs related to transport in Belgium. They are projected to be 94% higher in 2030 than in 2010, if a central value for the damage of greenhouse gas emissions is used, and this in spite of the fall in the emissions of all pollutants except the greenhouse gases. The growth is due to the increase in damage costs over time (due to changes in background concentrations, population and GDP per capita). The direct environmental costs account for 60% to 75% of the total environmental costs. The share of the environmental costs of freight transport is projected to grow between

2010 and 2030 (from 26% to 33%). Over time greenhouse gas emissions will account for an increasing share of the environmental costs (from 52.7% in 2010 to 69.1% in 2030).

5.3. Lessons learned from the LIMOBEL policy simulations.

Up to now the combination of models has been used to simulate the impacts of two policy scenarios.

The first simulation consists of a *kilometre charge on heavy duty vehicles* only, while in the second one the charge is also levied on *light duty vehicles and cars*. If the objective of charge is to reduce congestion and environmental costs, the results show that charging heavy duty vehicles alone does not appear to be efficient. While leading to a modal shift toward light duty vehicles, barges and trains, the shift towards light duty vehicles is dominant, which leads to an increase in congestion (due to the lower load capacity of light duty vehicles). The effect on total emissions is close to zero and the environmental damage of transport even rises (due to the increase in light duty vehicles).

To avoid this problem, charging heavy and light duty vehicles simultaneously is necessary. Furthermore, bearing in mind the importance of passenger road transport, charging cars too, as is done in the second simulation, leads to a significant improvement of congestion, more particularly in the peak period, and of the emissions (direct and indirect) generated by transport.

Concerning welfare, the analysis shows also the second simulation exercise leads to a welfare gain for society, if taxes are recycled through lower labour taxes. However, if taxes are recycled through a reduction in general taxation, the impact on welfare is negative for the levels of the kilometre charge that are considered in the simulation.

The fact that revenue recycling is an important determinant of the welfare impact of transport policies, is an important conclusion that can be drawn both from the analyses with the PLANET model and from the exercises performed with the Computable General Equilibrium model.

At this stage we are only able to present a limited number of simulations. However, the LIMOBEL framework is ready for additional simulations. A number of these simulations will be performed in the cluster project PROLIBIC, after consultation of the follow-up committee of that project.

5.4. Lessons from and for modelling

An important lesson is that the development of the LIMOBEL tools was complex but that we arrived at a usable modelling framework. In some cases, however, we had to downsize our ambitions somewhat. This gives rise to opportunities for further development, as discussed below for the different LIMOBEL models. Another conclusion that holds for all of these models is that in order to keep going in this direction, further efforts by statistical offices to gather data and to maintain data up-to-date are needed.

5.4.1. The PLANET model

For the PLANET model, the latest development concerns the integration of the vehicle stock module which allows to calculate the size and the composition of the car stock. From the detailed composition of the stock (by type of vehicles and size), a more accurate description of the emissions and the environmental damages can be calculated. Up to now, the decomposition of the stock of vehicles per type and size is based on a main variable, namely the desired stock of vehicles. This variable is obtained by dividing the number of vehicle-km obtained in the Modal and Time Choice module by the average annual mileage. In the current version of the PLANET model, this latter parameter is defined exogenously. Future developments of PLANET will address this issue. More precisely, the feasibility of defining the annual average mileage as an endogenous variable depending on the new composition of stock of vehicles and the annual mileage per type and per size of vehicles in the previous period, will be studied. Another likely development is to make the choice of the new car technologies (e.g. hybrid cars, electric cars) endogenous in the car stock module.

5.4.2. The Computable General Equilibrium Model

Up to now, the Computable General Equilibrium model developed in the LIMOBEL project is static, with a simplified representation of the labour market, and with one representative household per region. At least three points could be developed further. Firstly, the model should consider different types of representative households characterised by socio-economic indicators. The hypothesis behind the construction of several representative households per region is that households react differently to policies according to their socio-economic characteristics. A model with 2 types of households per region (low and high skilled) is under development. At this stage it is not yet sufficiently reliable to make policy analysis with it. Secondly, considering that the relation between labour market and households transport is not trivial, a CGE model with perfect competition could be considered as a good baseline, but may be insufficient for considering properly the relation between the labour market and transport. In particular, involuntary unemployment embedded in a search–and–matching framework may be more appropriate to describe interregional labour markets, especially if one seeks to make commuting endogenous. Thirdly, although a static CGE model is already able to bring important insights with respect to policy analysis (analysis of shocks), the construction of a dynamic CGE model is of interest in order to make long run projections and to study the interaction between transport and the economy (the feedback effect of transport activity on the economy is not possible with PLANET). In the next coming years, the merge of both models (PLANET and the CGE model) is considered to be a priority, the ultimate objective being to have a long run projection model of transport including the interaction between transport and the economy.

5.4.3. The network model

For the NODUS model the first lesson learned is linked to one of the problems we encountered. It is the difficulty to obtain databases which are consistent between each other. Indeed, as explained in Section 3.3.5, we had many problems with the data we received, especially for freight transport.

The second one is the complexity to create a model mixing freight and passenger transport. To solve this problem, the assignment methods implemented in NODUS were improved. We can now assign in a single step freight and passenger matrices.

Thirdly, there are possible methodological refinements. A method to take explicitly into account the lines and services (frequencies) was developed but, as explained in above, this would require a huge work in terms of resources (human and material resources) to implement this on large networks.

It was already clear that NUTS2 or NUTS3 data used for origin-destination matrices do not provide very pertinent results for the network model.

We learned also that, even at a NUTS5 granularity, the model still lacks precision as intra-communal flows are not taken into account. It appears that, at least for some transport modes, this is a too strong hypothesis.

Finally, it has been experienced that the use of static equilibrium assignment models is not appropriate for national networks (medium and long distance trips) on which annual demand data matrices are assigned. Indeed, equilibrium models assume that we take into account the capacity while, with annual matrices, we have no information about peak and off-peak. Our experience shows that multi-flow assignment techniques give much better results.

5.4.4. The E-motion model for environmental impact

For all transport modes (road, rail, inland navigation and maritime transport) the modules within E-motion have been updated and extended.

In the road module we implemented Copert 4 energy consumption functions for the conventional fuels (diesel, petrol and LPG). For the alternatives we integrated VITO's expertise (measurements and literature) and international network. Additionally for passenger cars, the results of the CO_2 monitoring and the effects of the CO_2 legislation are integrated. The road module has been validated.

The rail module has been updated with information from both the Belgian Railway Company and the Belgian railway infrastructure manager (Infrabel) taking into account the technological evolution of the rolling stock and the Ex-TREMIS study. As advised by the steering committee we tried to tune the rail module with the rail model of the Flemish Environmental Agency (VMM). The rail module has been validated. Furthermore, we are also able to calculate geographically distributed emissions.

For inland navigation we also developed an emission model to assess geographically distributed emissions. We started the validation process within LIMOBEL. Unfortunately, we could not finish the whole process; as a result we partly lean on results from the SUSATRANS project to provide the other models (partner) with fuel consumption and emission factors for inland navigation vessels. Within the cluster project PROLIBIC we are proceeding with the implementation of the inland navigation module of E-motion.

The maritime module was developed in LIMOBEL, based on the methodology of MOPSEA and Ex-TREMIS. All four Belgian harbours, as well as the Belgian Continental Shelf and the Dutch part of the river Scheldt are geographically covered. The maritime module has been used in SHIPFLUX.

We also updated the estimates of the marginal external costs per tonne of $PM_{2.5}$ and NO_x emissions. For the other pollutants a literature review was made. For future years we took into account the change in the background concentrations and the demographic projections.

Finally, it would be magnificent to run all modules of E-motion simultaneously. However, the different input and output formats make this too complex to establish. So, we choose to run the different modules separately. Furthermore, we determine that it is very important to keep our models up to date with the latest historical information and scientific knowledge to ensure reliable results also on a rather short time horizon.

6. DISSEMINATION + VALORISATION

6.1. Policy support

The PLANET model is used for policy support for the Belgian FPS Transport and Mobility. It is used to construct reference scenarios for the future development of transport in Belgium and for the evaluation of policy scenarios.

The Federal Planning Bureau and VITO both used their models to contribute to the preparation of future scenarios for the environment and transport in Flanders. This was done in the framework of the "Milieuverkenning 2030" of the "Vlaamse Milieumaatschappij" and of the new Mobility Plan for Flanders of the Department "Mobiliteit and Openbare Werken".

Updated fuel consumption and emission factors that were developed within LIMOBEL have been applied in other SSD projects (BIOSES and CLEVER).

6.2. LIMOBEL workshop

In the spring of 2011 the final LIMOBEL workshop will be organised to present the results of the project. The workshop will be combined with the consultation of the stakeholders for the cluster project PROLIBIC in order to maximize the synergies between the two projects.

6.3. Presentations at policy seminars/workshops

During the course of the LIMOBEL project, the LIMOBEL partners presented their work at a number of policy seminars and workshops. A selection is given below:

- 2 February 2007: presentation on emission modelling for transport - Short overview and future research topics?, Open workshop 'The valorization of transport models to enable sustainable transportation, Organised by the Belgian Science Policy, Brussels (I. De Vlieger & L. Int Panis),
- 4 October 2007: invited expert at the international conference "Up stream conference, What will inland navigation look like?", organised by Promotie Binnenvaart Vlaanderen with the support of the European Commission. Intervention on "Without urgent measures, does inland navigation risk losing its pole position as the most environmentally friendly transport mode? " Brussels (I. De Vlieger).
- 19 November 2007: invited expert at the ad-hoc meeting on "Emission inventories improvement.", organised by IES-JRC EC, Ispra, Italy, (I. De Vlieger)

- 9 July 2008: "Transportfiscaliteit, Presentatie voor de Federale Raad voor Duurzame Ontwikkeling" (I. Mayeres)
- November 2008: invited expert at the round table of Flanders Inland Shipping Network (FISN). Contribution on the environmental performance of inland navigation vessels, Evenement organised by Waterwegen en Zeekanaal NV, Brussels. (I. De Vlieger)
- 25 February 2009: participation to panel discussion on "greening transport & inland navigation", European Barge Union (I. Mayeres)
- 18 May 2009: Rondetafel Logistieke toekomst voor Vlaanderen, Provinciehuis Leuven: feiten en cijfers over de sector logistiek en transport, de evolutie van het fileprobleem en de daarmee gepaard gaande klimaat- en gezondheidseffecten. (I. Mayeres)
- 8 October 2009: B-mobility day, Langetermijnvooruitzichten voor transport in België: Referentiescenario (I. Mayeres)
- 22 January 2010: "De rol van hernieuwbare energie in transportscenario's voor 2020 en 2030", ENOVER workshop (I. De Vlieger)
- 3 June 2010: Feasible vehicle and fuel technologies for 2020, European Parliament, ALDE Seminar, Transport in Europe 2020. A key element for sustainable growth (I. De Vlieger)
- 25 November 2010: "The Impacts of Different Theoretical Road Pricing Schemes in Belgium", Seminar on "The internalisation of external transport costs: what are the prospects for after 'Eurovignette II?', European Economic and Social Committee (I. Mayeres and M. Vandresse)

6.4. Presentations at scientific conferences/workshops

A list of the presentations at scientific conferences/workshops (in chronological order) is given below:

Schrooten, L. , I. De Vlieger, L. Int Panis, C. Cosimo and E. Pastori (2007), Emissions of maritime transport: a reference system, 5th International Congress on Maritime Technological Innovations and Research, Barcelona, November 2007.

Schrooten L., De Vlieger I., Int Panis L., Broekx S. (2007) Forecasting maritime emissions: an activity based approach, Paper presented at Transport - The Next 50 Years, July 2007, Christchurch, New Zealand.

Jourquin, B., J. Lechien and J. Pinna (2008), Lines and Services in a Strategic Multi-modal Freight Network Model - Methodology and Application, paper presented at the 48th Congress of the European Regional Science Association,27 – 31 August 2008, Liverpool, UK

De Vlieger, I., B. Jourquin, I. Mayeres and F. Pietquin (2009), LIMOBEL - Long-run Impacts of policy packages on MObility in BELgium: Development of a modelling tool, paper presented at the BIVEC Transport Research Day 2009.

Mayeres, I. and M. Nautet (2009), Perspectives à long terme du transport en Belgique. Scénarios alternatifs“, Belgisch Wegencongres, 23 September 2009.

De Vlieger, I., D. Dewaele,B. Jourquin, I. Mayeres, H. Michiels, L. Schrooten, M. Vandresse, A. Van Steenbergen (2010), LIMOBEL – Long-Run Impacts of Policy Packages on Mobility in Belgium: Development of a Modelling Tool, paper presented at the 12th WCTR Conference, Lisbon, Portugal.

Mayeres, I., M. Vandresse and A. Van Steenbergen (2010), A Long-Term Regional CGE Model Focused on Transport Issues in Belgium, paper presented at the 12th WCTR Conference, Lisbon, Portugal.

Michiels H., F. Deutsch, L. De Nocker, S. Broekx, L. Van Esch and L. Int Panis (2010), Human Health Impacts of $PM_{2.5}$ and NO_x Transport Air Pollution in Belgium. Presentation at the 31st NATO/SPS International Technical Meeting on Air Pollution Modelling and its Application, Torino, Italy, 27 Sep – 1 Oct 2010.

Vanhulsel, M., J. Vankerkom, L. Schrooten, I. De Vlieger, B. Degraeuwe, K. Dierckx and H. Michiels (2010), E-Motion: An Environmental Impact Assessment Modelling Framework, poster presented at TAP2010, Zürich.

Mayeres, I. and S. Proost (2011), The Taxation of Diesel Cars in Belgium – Revisited, paper submitted to the BIVEC Transport Research Day and the IAEE Conference.

7. PUBLICATIONS

7.1. Peer review

Mayeres, I. and S. Proost (2011), The Taxation of Diesel Cars in Belgium – Revisited, paper submitted to Energy Policy.

Schrooten L., De Vlieger I., Int Panis L., Styns K., Torfs R. (2008) Inventory and forecasting of maritime emissions in the Belgian sea territory, an activity based emission model / Atmospheric Environment 42(4), 667-676.

Schrooten L., I. De Vlieger, L. Int Panis, C. Chiffi and E. Pastori (2009), Emissions of maritime transport: A European reference system, Science of the Total Environment 408, 318–323.

7.2. Presentations at conferences/workshops

De Vlieger, I., B. Jourquin, I. Mayeres and F. Pietquin (2009), LIMOBEL - Long-run Impacts of policy packages on MObility in BELgium: Development of a modelling tool, paper presented at the BIVEC Transport Research Day 2009.

De Vlieger, I., D. Dewaele,B. Jourquin, I. Mayeres, H. Michiels, L. Schrooten, M. Vandresse, A. Van Steenbergen (2010), LIMOBEL – Long-Run Impacts of Policy Packages on Mobility in Belgium: Development of a Modelling Tool, paper presented at the 12th WCTR Conference, Lisbon, Portugal.

Jourquin, B., J. Lechien and J. Pinna (2008), Lines and Services in a Strategic Multi-modal Freight Network Model - Methodology and Application, paper presented at the 48th Congress of the European Regional Science Association,27 – 31 August 2008, Liverpool, UK

Mayeres, I. and M. Nautet (2009), Perspectives à long terme du transport en Belgique. Scénarios alternatifs“, Belgisch Wegencongres, 23 September 2009.

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Presentation at the 31st NATO/SPS International Technical Meeting on Air Pollution Modelling and its Application, Torino, Italy, 27 Sep – 1 Oct 2010.

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7.3. Other

VMM (2009), Milieuverkenning 2030, Hoofdstuk Transport, pag. 131-154. (E-Motion road partly developed within LIMOBEL has been valorised) http://www.milieurapport.be/nl/publicaties/milieuverkenning-2030/hoofdstuk-6/

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10. LIST OF ANNEXES

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Annex 5: Enquête budget des ménages : analyse descriptive des dépenses et des revenus par type de ménages : 2002-2006

Annex 6: The networks of the NODUS model

Annex 7: Minutes of the follow-up committees

THE ANNEXES ARE AVAILABLE ON THE WEBSITE

http://www.belspo.be/belspo/ssd/science/pr_transport_en.stm