Annex 2 to the final report of the **LIMOBEL** project (Long run impacts of policy packages on mobility in Belgium), study financed by the Belgian FPS Science Policy.
(Contract SD/TM/01B)

REPORT

LIMOBEL Annex 2 – External Environmental Cost Model for Transport

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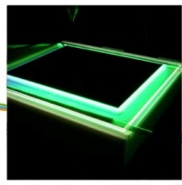

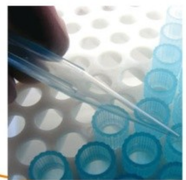

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EXECUTIVE SUMMARY

We discussed the most important external cost categories from transport. Regarding external costs of air pollution, we analysed impacts on human health and on buildings. External costs from climate change and noise were examined as well. The most important task was to obtain marginal figures for a set of pollutants. We did a very detailed analysis for human health impacts of PM2.5 and NO_x, whereas for the other pollutants and impact categories, we resorted to literature.

The reason for doing our own calculations for PM2.5 and NO_x lies in the variation of the background concentrations. In other words, we wanted to predict how the external air pollution cost changed, following a variation in general air quality.

The marginal external cost (MEC) calculation for human health impacts started from the notion that marginal cost figures can only be derived when both a baseline scenario and an alternative scenario is tested. The difference between these two scenarios is that the latter starts from a changed transport emission level of one particular pollutant. The result is a difference in external costs between the two scenarios. We divided this result by the emission difference in order to derive the MEC of each pollutant. We followed this procedure for the major transport pollutants PM2.5 and NO_x. Concerning the other transport pollutants like SO_2, NMVOC and PM10, we determined our cost figures on the basis of the available literature.

Our analysis (for human health impacts from PM2.5 and NO_x) is based on the impact pathway method, as developed within the ExternE projects. In this approach, we started from Belgian emission data from our emission model E-motion, calculated concentration maps with the air quality model BelEUROS, took into account the exposed population, and used the result in the DALY-calculator model to find out how big the impacts and costs are.

The resulting external cost per tonne (MEC) of transport-related PM2.5 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. The resulting numbers are plausible in the light of the ExternE results found by Friedrich & Bickel (2001) and the numbers published in IMPACT (2008). For NO_x though, the external cost per tonne of emission is about 2.5 and 2.2 kEUR for the years 2020 and 2030. However, for 2007 the model results in a total cost of -4.2 kEUR, i.e. a marginal external benefit.

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 in this report 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 LTO cycle for air traffic. We executed our own scenario calculations for the years 2007 (as a proxy for the current situation), 2020 and 2030.

In our calculations, we took into account a Western European population growth rate which is based on the population outlook of the Belgian Federal Planning Bureau (FPB, 2009). We updated the impact calculation and monetization steps by using the most recent information on concentration-response functions and willingness-to-pay values from European projects as ExternE (2005), CAFE (2005a) and NEEDS (2006, 2007a, 2009), with updates for the specific Belgian case (Franckx et al., 2009).

In a recent study (MIRA, 2010), we estimated marginal external cost figures as well, for emissions in Flanders instead of Belgium. We suggested to use the numbers presented there for the evaluation of emissions other than PM2.5 and NO_x.

The result of this exercise is a table with marginal external cost figures for a set of pollutants and scenario years.

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List of Acronyms

BAU	Business As Usual
CO_2eq	CO_2 equivalents
DALY	Disability Adjusted Life Years
dB	decibel
EEC	External Environmental Cost
E-motion	Energy and emission model transport (VITO)
ENV-EUR	Monetization module from external environmental cost model (VITO)
FPB	(Belgian) Federal Planning Bureau
ktonne	1000 tonne
L_{den}	Noise level measure over day, evening and night, with greater weight for evening and night
kEUR	kilo euro = 10^3 EUR
LTO	Landing and takeoff cycle
MEC	Marginal External Cost
MEUR	million EUR = 10^6 EUR
Nitr 2.5	Nitrate aerosols ≤2.5µm
NSDI	Noise Sensitivity Depreciation Index
PF	Particulate filter
SIA	Secondary Inorganic Aerosols
Sulph 2.5	Sulphate aerosols ≤2.5µm
VOLY	Value of a life year
WTP	Willingness-to-pay
YOLL	Years of life lost
yr	year

LIST OF SYMBOLS

NH_4NO_3	Ammonium nitrate
$(NH_4)_2SO_4$	Ammonium sulfate
NO_3^-	Nitrate ion
NO_x	Nitrogen oxide
PM2.5	Particulate matter with an aerodynamic diameter ≤2.5μm
PM10	Particulate matter with an aerodynamic diameter ≤10μm
PMcoarse	Particulate matter with an aerodynamic diameter 2.5-10μm
SO_2	Sulphur dioxide
SO_4^{2-}	Sulphate ion
VOC	Volatile organic compound

CHAPTER 1 INTRODUCTION

1.1 Context

The acronym LIMOBEL stands for "Long-run impacts of policy packages on mobility in Belgium". This project is part of the research programme Science for a Sustainable Development (SSD2) financed by the Belgian Federal Public Planning Service.

The aim of LIMOBEL is to develop a fully operational modelling tool to study the impact of transport policies on the economy and on emissions in order to help the government that is facing different objectives, to make choices. The project will produce long-term projections (up to 2030) of passenger and freight transport demand in Belgium. A baseline scenario will be constructed which will be compared with alternative policy scenarios for a more sustainable transport. In the alternative policy scenarios, packages of instruments will be considered, including pricing instruments, regulation and infrastructure measures.

This report is the result of Task 4.6 of LIMOBEL "External environmental cost model for transport".

1.2 Objectives

The objective was to refine and update the external environmental cost model. Compared to previous research we now took into account the change in background emissions and concentrations, and demographic evolution. Furthermore, we updated data and scientific information regarding the dispersion and transformation of emitted pollutants, concentration-response relations and monetary evaluation. In addition, a set of environmental external costs due to maritime transport is presented.

1.3 Acknowledgment

Firstly, the authors would like to acknowledge the Belgian Federal Public Planning Service and the Flemish Environmental Agency (VMM) for giving VITO the opportunity to do this research. Starting from the results of LIMOBEL, VITO could further extend its expertise on external costs of transport within a project for the Flemish Environmental Agency (MIRA, 2010). There has been a feedback between both projects.

Furthermore, the authors wish to express their gratitude to their VITO colleagues Felix Deutsch, Steven Broekx and Leo De Nocker, who placed their expertise in the service of LIMOBEL.

1.4 Bookmarker

Chapter 2 describes the methodology of external environmental costs of transport. In Chapter 3 to 6 we successively present the results on external environmental cost of air pollution, climate change, noise and maritime transport. Finally, in chapter 7 we present the general conclusions.

CHAPTER 2 METHODOLOGY EXTERNAL ENVIRONMENTAL COST MODEL FOR TRANSPORT

In this section, we give an overview of the methodology followed to calculate the external environmental costs of transport. External costs of transport are frequently subdivided into three broad categories: external environmental costs (EECs), external congestion costs and external accident costs (Figure A). Although the last two categories constitute a significant part of total externalities, work package 4 of LIMOBEL only looked at the EECs.

2.1 Categories voor EECs for transport

The most obvious categories of EECs for transport are air pollution, climate change and noise. The impact categories through which air pollution acts as an external cost are for example: human health, buildings, ecosystems and agricultural crops. Noise and climate change are evaluated only briefly in this report, whereas the impact of air pollution on human health is elaborated more thoroughly. For air pollution impacts on buildings, we give an expert judgement on external cost valuations, based on ExternE methodologies. Impacts on ecosystems and agricultural crops are not evaluated in this report.

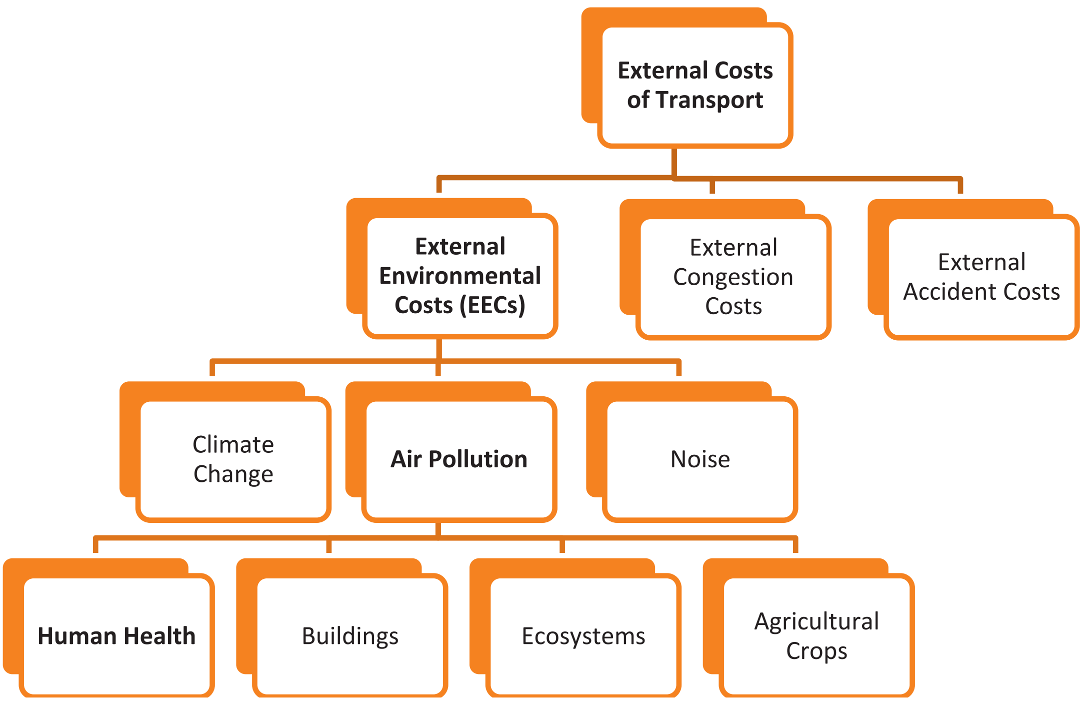


Figure A: External costs of transport and their underlying damage categories

We mainly focus on human health effects of air pollution. The goal of this study was to calculate an marginal external cost (MEC) for air pollution from Belgian transport for two pollutants: NO_x and PM2.5. For the other harmfull emissions, a literature review was performed.

2.2 Impact pathway approach

We decided to follow the Impact Pathway Framework (ExternE, 2005) in order to calculate these externalities. Conducting this approach, we start from Belgian emission data from our transport emission model E-motion, calculate concentration maps with the air quality model BelEUROS, take into account the exposed population, and use the result as an input in our DALY-calculator model to find out how big the impacts and costs are. Figure B gives a clear overview of these steps, with the models used indicated on the right-hand side.

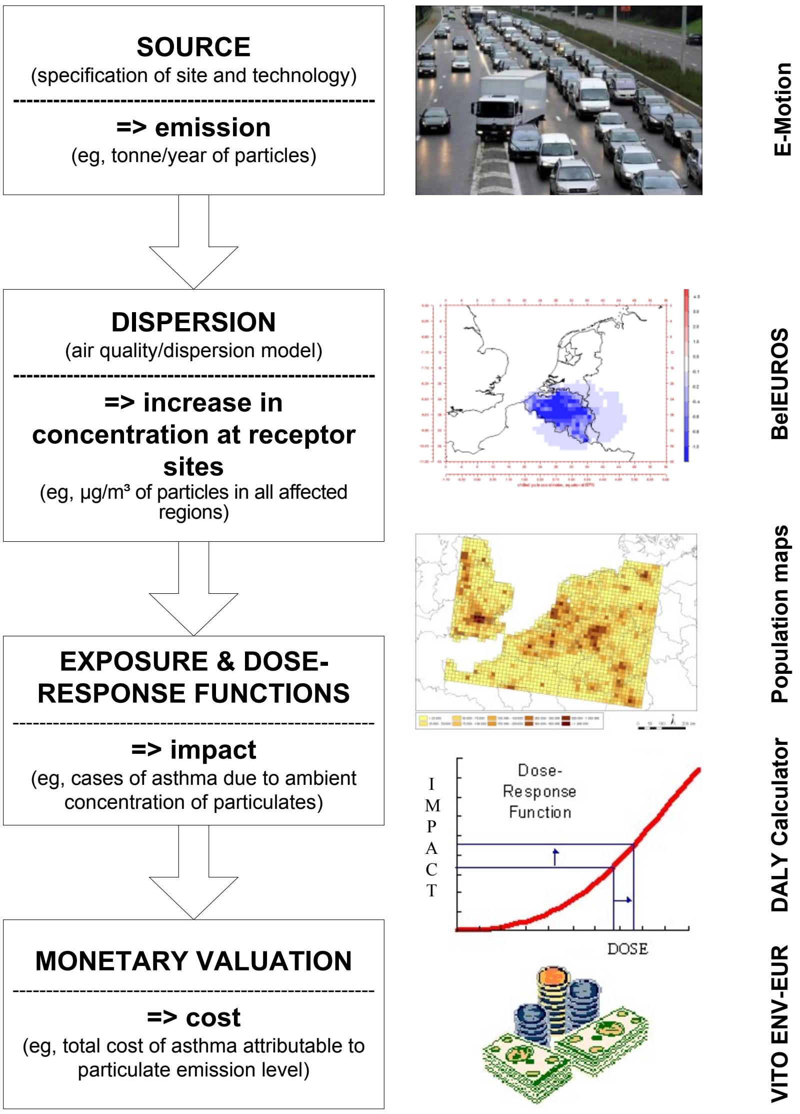


Figure B: Impact Pathway Approach for transport

2.3 Future background concentrations

In previous studies the effect of the changing background emissions, influencing the chemical transformation of transport emissions in the atmosphere, was not taken in account. Within this study we did take into account realistic background emissions up to 2030. We did so because the fate of 1 g of e.g. NO_x in 2010 and 2030 will be completely different in terms of the amount of secondary PM formed, as well as in terms of its effect on ozone titration (Int Panis, 2008).

For the different scenario years, our evaluation is based on separate background concentrations. These background concentrations are not clearly defined a priori, as they originate from the emission levels for the complete set of pollutants for the whole of Europe.

The root emission scenario is the 'NEC2007 baseline current legislation' from IIASA, as used in MIRA (2009d). This can be considered as the most recent available emission scenario for all European countries, based on the status of European emission policies of the year 2008. Consequently, our scenario for 2007 is based on the IIASA-baseline for 2007 and the 2020 scenario is based on IIASA 2020 (the predicted European emissions for 2020, as part of 'NEC2007…'). Note that the MIRA (2010) report is different from the original NEC2007 scenarios in the sense that VMM values were used there for emissions in Flanders (instead of the original IIASA country emissions). The uncertainty is higher for emissions in 2030, as IIASA does not suggest any value here. Therefore, the 2030 emissions are based on extrapolations of the emissions for Flanders (provided by VMM) in 2020. It is to say, the trend in Flemish emissions by pollutant by sector between 2020 and 2030 was applied to the emissions in 2020 for all European countries by pollutant and by sector.

2.4 Marginal damage cost

The correct way to calculate a marginal damage cost (or marginal external cost, MEC) for a tonne of a pollutant is to decrease the emission of this pollutant by a small amount to look how external costs react. As our study subject is the transport sector in Belgium, we decided to simulate a 20% decrease in the Belgian transport emissions, for one pollutant at a time in each scenario (PM2.5 or NO_x). A 20% decrease can still be considered as an amount of marginal size. However, this change is large enough to result in an altered set of concentration values. We simulated three scenario years: 2007, 2020 and 2030, taking into account the changing background concentrations in the future. The three scenarios are displayed in Table i:

sample year/emissions	**BAU**	**-20% PM2.5**	**-20% NO_x**
2007	2007BAU	2007PM2.5	2007NOx
2020	2020BAU	2020PM2.5	2020NOx
2030	2030BAU	2030PM2.5	2030NOx

Table i: Overview of the 3 scenarios

The restriction to the two pollutants PM2.5 and NO_x exists because of the fact that a unit increase in the number of pollutants under investigation would increase the number of BelEUROS model runs by three (i.e., one for each scenario year), which would be very time consuming. So, marginal impacts for other pollutants than PM2.5 and NO_x (e.g., SO_2, PM10, VOC,…) are not tested in this study. In others words, their presence is taken into account in each scenario, but no separate scenarios have been tested for them. The limitation to PM2.5 and NO_x is defensible because these are the two most important pollutants from low sources like traffic. Marginal external costs caused by the other pollutants are described through a short literature review further in this report.

Note that in this set up, "Belgian transport emissions" include road transport, railway transport and inland navigation as well as movements from seagoing vessels between the Belgian ports of the North Sea (Antwerp, Zeebruges, Ostend, Ghent). Air traffic emissions from the landing and takeoff (LTO) cycle are included too.

It should be mentioned that we calculate an average external cost for the whole of the Belgian territory, since we were not able to differentiate between a tonne of pollutant emitted in urban areas versus rural or highway areas. However, this is absolutely necessary to induce a place-dependent marginal emission change computation. Instead, we worked with the marginal change of emissions throughout the whole of Belgium. Consequently, the external cost figures calculated in this report represent a valuation per tonne, averaged over all types of emission locations. Please keep this in mind while considering the results, since it is clear that externalities per tonne of a pollutant emitted in urban areas will be higher than a tonne of the same substance emitted in less densely populated areas.

CHAPTER 3 MARGINAL EXTERNAL ENVIRONMENTAL COST OF AIR POLLUTION

External costs from air pollution affect human health, buildings, ecosystems and agricultural crops. In this report, we will focus on the first two categories. We thoroughly describe the impacts through human health, because the methodology for this class is most clear. Marginal effects on building materials are based on numbers from the literature.

3.1 Human Health

We start the discussion of the results with the human health impacts of air pollution. Indeed, this is the part we know most about and which is responsible for a large share of total EECs.

We will first describe the current state of knowledge concerning the human health impacts of the pollutants considered in our research, i.e. PM2.5 and NO_x. At a later stage, this will give us the opportunity to compare these with our own results.

External costs from transport attributable to PM2.5 range in the literature from 15.2 kEUR/tonne (Rabl, 2008) for rural areas to 422.2 kEUR/tonne (IMPACT, 2008) for metropolitan areas. For NO_x, we find values for transport ranging between -2 kEUR (MIRA, 2000) for impacts through ozone and 8 kEUR/tonne (EC Transport, 2000) for impacts through other pollutants. These intervals are so broad because of the range of assumptions lying underneath.

Indeed, these indicators are dependent on a complete set of factors: emission location (related to population density), stack height (low for transport), concentration-response functions used, categories of air pollution included (sometimes more than only human health), concentration pollutants considered (cfr. nitrates versus ozone impacts of NO_x), and modelling methodology and assumed background concentrations.

All things considered, it is reasonable to assume an external cost for Belgian PM2.5 which ranges between 91.1 kEUR (rural) and 136.2 kEUR (urban) per tonne emitted (IMPACT, 2008). For NO_x, we expect positive values for impacts through nitrates and negative values (i.e., external benefits) for impacts through ozone.

The reason for doing our own calculations lies in the variation of the background concentrations. In other words, we want to predict how the marginal external air pollution cost changes, following a variation in general air quality. We decide to follow the steps from the Impact Pathway Approach in order to distil the results.

3.1.1 Emissions

Behind each of the three scenarios, there are multiple assumptions concerning vehicle fleet, vehicle kilometers, activity location, meteorological conditions, etc. That is why each scenario comes up with different emission results, as shown in Figure C and Figure D. It should be mentioned that these graphs do not only contain transport emissions, but also emissions from the other sectors.

Note that in BelEUROS, meteorological conditions do change throughout the course of a year, but these conditions are the same for the various scenario years. Hence, no such predictions for the future are included. Consequently, climate change assumptions are neglected in the air quality model. An exception to this is the background ozone concentration, which is assumed to rise steadily in the coming years.

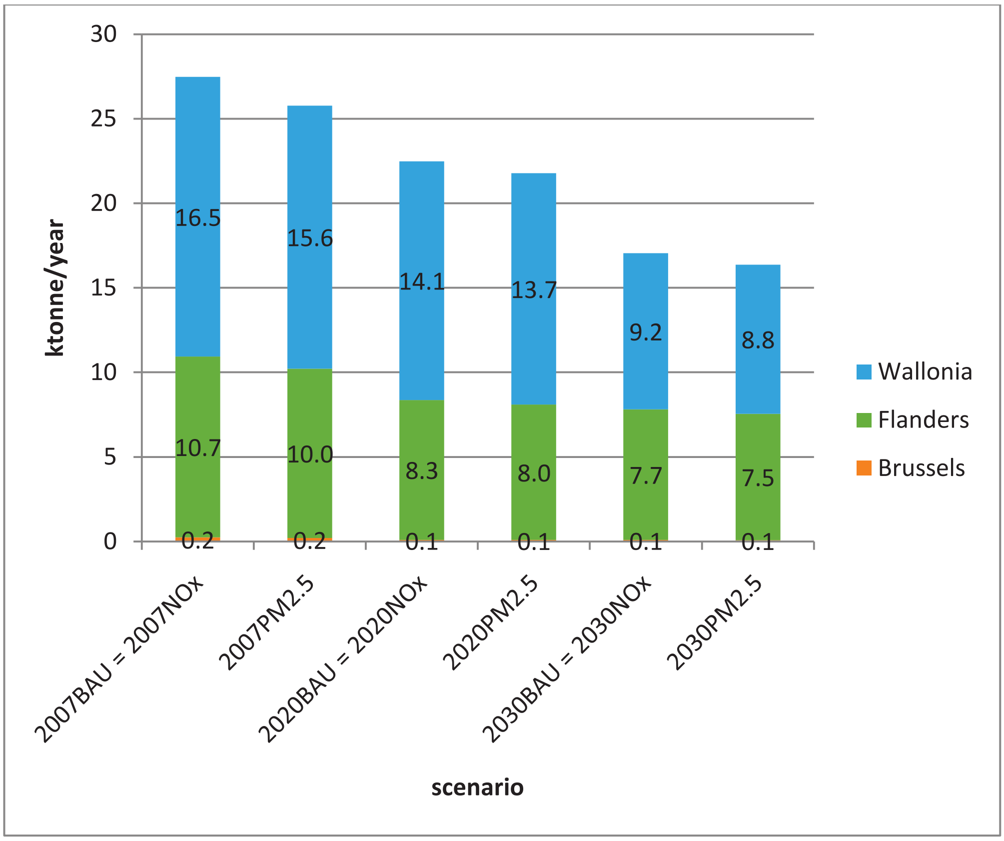


Figure C: Emission level for PM2.5 in the 3 regions for the 3 scenarios

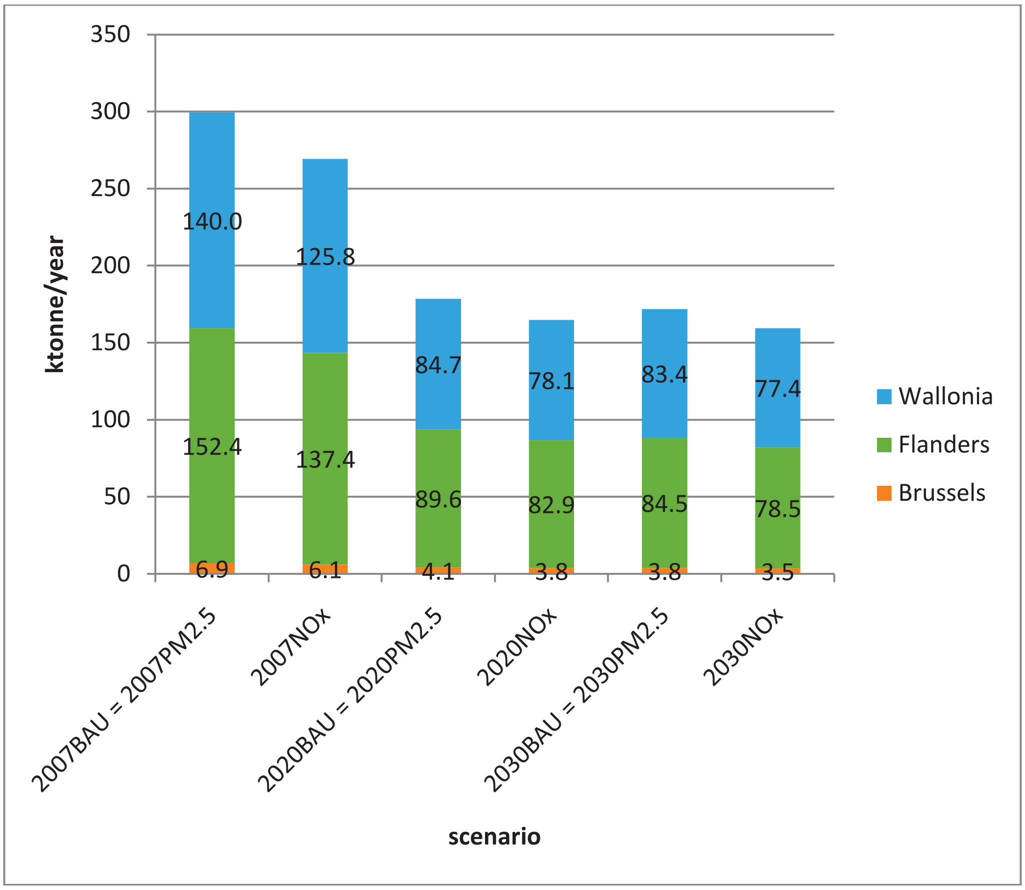


Figure D: Emission level for NO_x in the 3 regions for the 3 scenarios

3.1.2 Concentrations

These emissions are inputs for the BelEUROS atmospheric dispersion model, which is run in a second step. Each of the two ‘differentiating scenarios’ (i.e., the non-BAU scenarios) lowers the transport emissions of one of the two pollutants by 20% compared to its initial transport emission level. It is interesting to see how concentrations in a differentiating scenario change relatively vis-à-vis the BAU scenario. Five concentration pollutants have been studied: ozone, PM10, PM2.5, sulphates and nitrates.

In this methodology, for reasons of simplification we consider all non-exhaust PM2.5 emissions as being exactly as harmful to human health as exhaust PM2.5.

We further assume that all sulphates and nitrates react with ammonia to form the secondary aerosols ammonium sulphate or –nitrate. Therefore, the concentration output for NO_3^- groups (from BelEUROS) can be multiplied by a factor 1.29 in order to find the concentration of the secondary aerosol NH_4NO_3. This immediately follows from the ratio of molecular masses from NH_4NO_3 and NO_3^-, i.e. 80/62. An analogous argument holds for converting SO_4^{2-} groups to $(NH_4)_2SO_4$. For that purpose, we use a conversion factor of 132/96 = 1.375. When looking at size, the majority of the sulphate and nitrate aerosols can be classified under PM2.5, so here they will always be reported as being a subclass of PM2.5, besides primary PM2.5 (called ‘PM2.5 pr’ in the scenario runs). According to a test done by VITO in September 2010, those two assumptions (i.e., both the theoretical computation of NH_4^- concentrations and the fact that all secondary pollutants are smaller than 2.5µm) do not result in any marginal external cost difference compared to a fully separate calculation of both NH_4^- groups and the secondary coarse fraction. In contrast with earlier studies in ExternE (2005), secondary pollutants are now considered exactly as harmful as primary PM2.5, following NEEDS(2007a).

In the scenario where PM2.5 transport emissions are lowered, we notice a large effect in overall PM2.5 and PM10 concentration levels. For the scenario with decreased NO_x transport emissions, there is a significant relative change in total ozone concentrations and a smaller relative effect on total nitrate and sulphate formation. We refer to Figure E till Figure J below for the resulting 15 (= 2*3 + 3*3) detailed concentration maps. Note that the PM2.5 figures (Figure E till Figure G) do contain the complete PM2.5 fraction, i.e. with secondary pollutants included.

It should be clear that for the various scenario years, the relative difference compared to the BAU scenario (red for an increase, blue for a decrease) can change considerably.

It is to say, the impact of a 20% decrease in **PM2.5 emissions** from transport has a much greater relative impact on <u>PM2.5</u> concentrations in 2007 than in 2020 or 2030. It is to say, in 2007, a large part of Belgian grid cell concentrations drops by more than 1 percent, and the area that falls more than 0.1% ranges fairly well across the borders, unlike the scenario years 2020 and 2030. A possible explanation is the fact that total particle emissions are expected to decrease in future years, so the impact of a 20% decrease on a smaller total will also result in a smaller concentration. The relative impact on total <u>PM10</u> concentrations is also more pronounced for the earlier scenario years.

Looking at the effects of a 20% fall in transport related **NO_x emissions**, we notice a relative increase in <u>ozone</u> concentration of 4-10% around the large traffic axes (Brussels-Antwerp, Brussels-Ghent). Areas far across the borders, mainly towards the east, are affected by ozone level increases of over 0,3%. This contrasts with 2020 and 2030, where almost all the effects above 0.3% are limited to the Belgian territory. <u>Sulphate</u> concentrations are also increasing as a result of the lowered NO_x emissions, albeit not as extreme as with ozone. The largest relative differences amount to 0.6-1.0% (western part of Belgium). The area affected by an increase above 0.3% goes far beyond the borders for the 2007 scenario, unlike the 2020 and 2030 scenarios, where none of the studied cells displays an effect over 0.3%. <u>Nitrate</u> concentrations seem to decrease more in 2020 compared to 2030 and definitely compared to 2007. The gravity pith is situated below the language border with relative drops of more than 1%, while the effects (decrease greater than 0.1%) stretch to large parts of Western Europe.

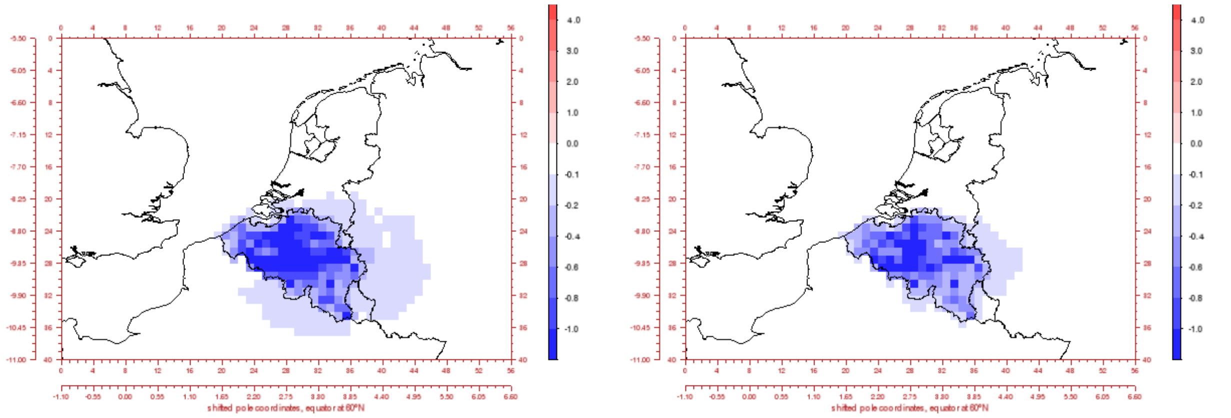


Figure E: Relative concentration differences (%) 2007BAU versus 2007PM2.5 for PM2.5 (left) and PM10 (right)

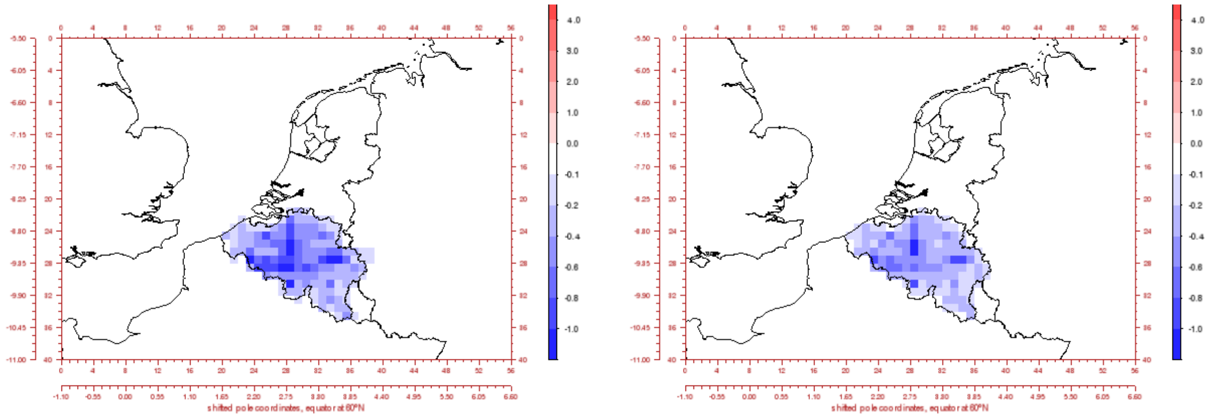


Figure F: Relative concentration differences (%) 2020BAU versus 2020PM2.5 for PM2.5 (left) and PM10 (right)

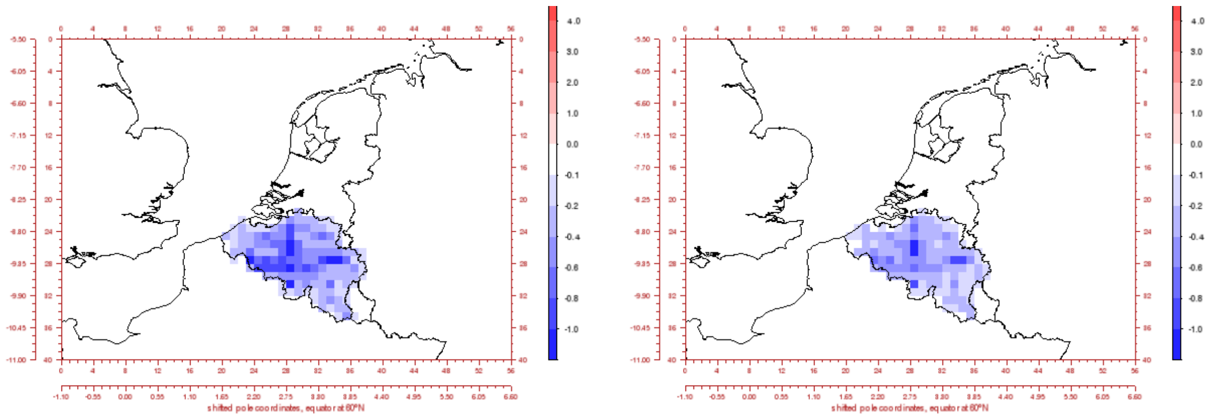


Figure G: Relative concentration differences (%) 2030BAU versus 2030PM2.5 for PM2.5 (left) and PM10 (right)

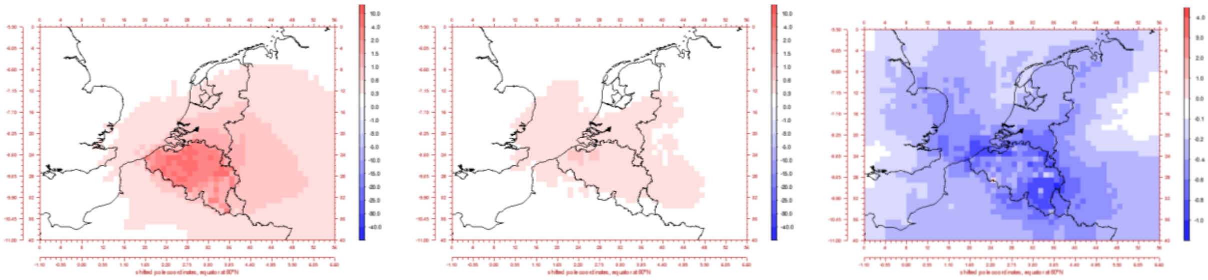


Figure H: Relative concentration differences (%) 2007BAU versus 2007NOx for O_3 (left), sulphates (middle) and nitrates (right)

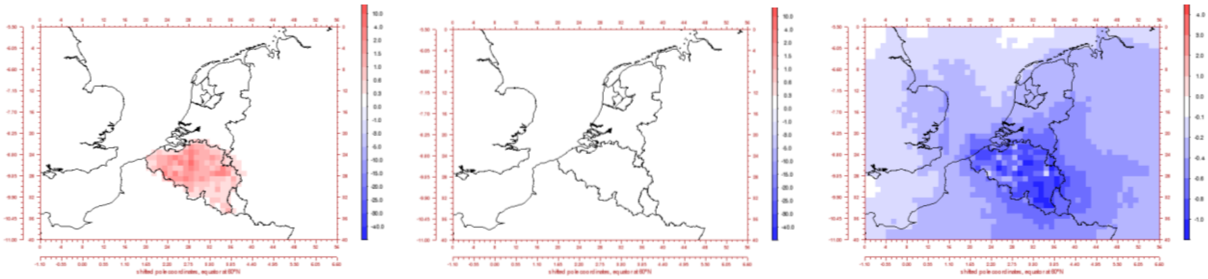


Figure I: Relative concentration differences (%) 2020BAU versus 2020NOx for O_3 (left), sulphates (middle) and nitrates (right)

Figure J: Relative concentration differences (%) 2030BAU versus 2030NOx for O_3 (left), sulphates (middle) and nitrates (right)

The share of transport in overall emissions can differ for the different pollutants. It is to say, the relative effect on some pollutants (see figures) is so small because the underlying transport emissions are only a fraction of total emissions. Consequently, the maps given above are only meant to illustrate the sign of the correlations and the range of grid cells used.

3.1.3 Exposure

In a third step, we look at the exposure of population in the 'hot spot'. This is how we call the area around Belgium, which should include the majority of the marginal external cost impacts originating from Belgium. We assume that in our scenarios, no effects on human health occur beyond this hot spot. On the other hand, it is clear that every possible effect for a person within the hot spot is included in our calculations. In order to calculate the number of people exposed, we use a European population map based on the census 2001 (see Figure K). This map has a 15x15 km resolution, which corresponds to the concentration maps calculated in the previous step.

The population map was constructed using a cut from the raster map 'Population density grid of EU-27+, version 5' from the Joint Research Centre (EEA, 2009). The dasymetric mapping technique and a support map were used in order to accurately distribute the population data, known per city from the Census 2001 from Eurostat. This support map is the land use map Corine Land Cover 2000 (CLC), version 9, which was reclassified to nine categories to which population was assigned in different proportions. Just like the CLC map, the resulting population density map consists of a grid with a resolution of 100m. Because the concentration values are available on a grid of 15 by 15 km cells, the finer cells of the population map were aggregated to the same (more coarse) resolution.

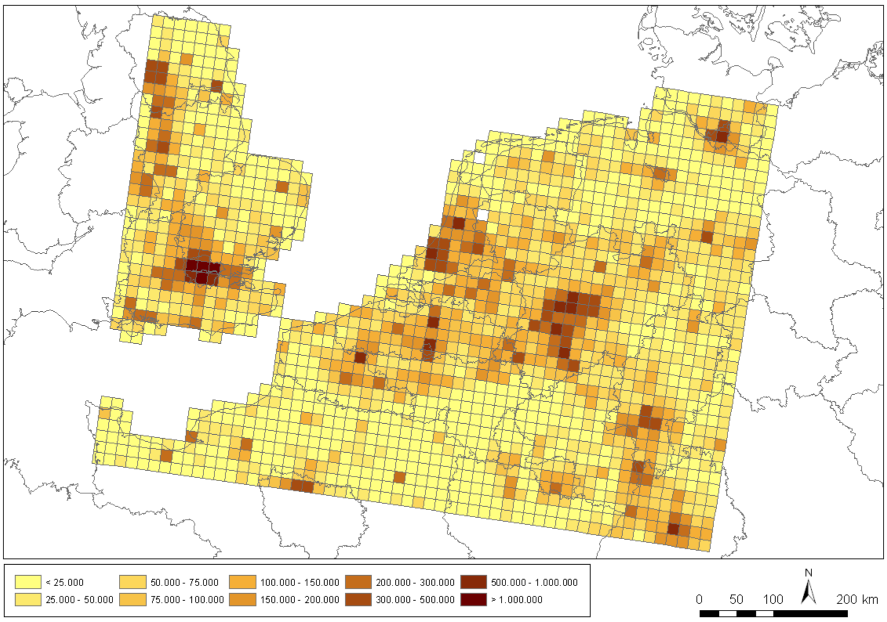


Figure K: Population numbers per grid cell for 'hot spot' in 2001

In order to estimate the size of the hot spot population for the years beyond 2001, we use the annual population growth and age distribution, available in the recently updated demographic prognoses for Belgium (FPB, 2009). This is done in Figure L and Figure M. Thus, the known data from the census 2001 (blue dot in Figure L) are extrapolated for the other years by means of the predicted demographic evolution for the whole of Belgium. So, we assume that the hot spot population evolves in exactly the same way as the Belgian population is expected to. The resulting total projected population growth is displayed in Figure L, whereas the relative evolution over the different age classes is given in Figure M.

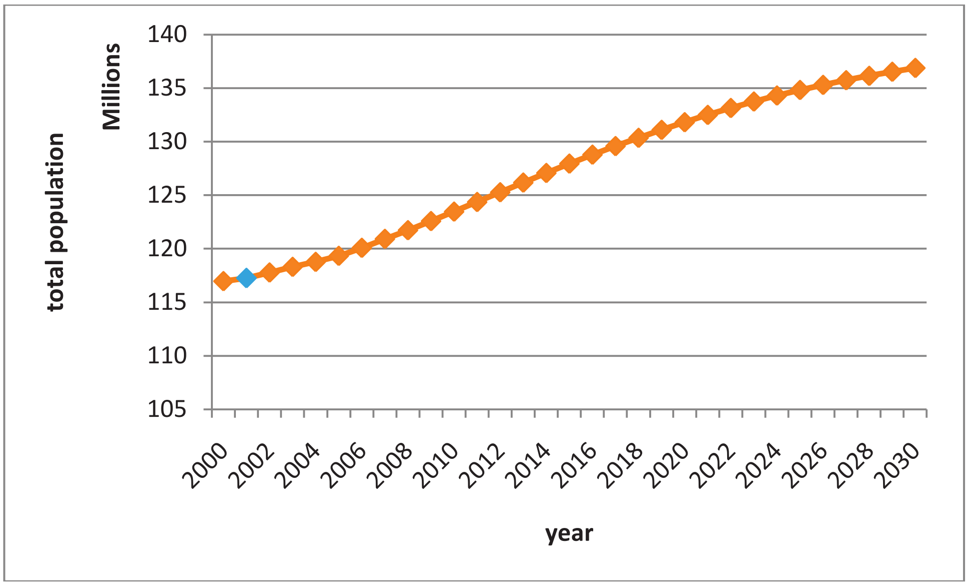


Figure L: Forecast of total population in the hot spot, based on FPB predictions for Belgium

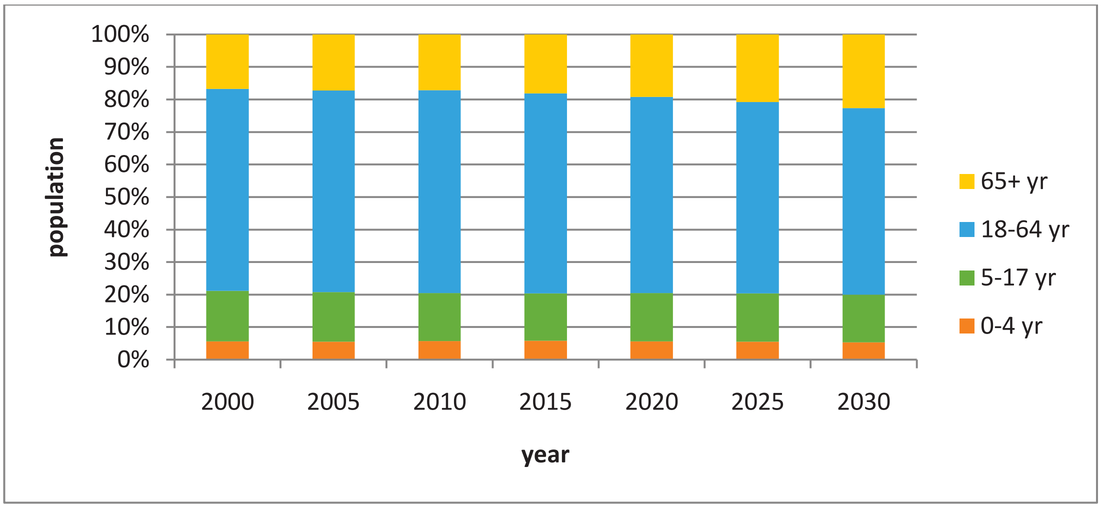


Figure M: Hot spot relative age class distribution for some example years

3.1.4 Impact

As we now dispose of concentration and population maps with the same resolution, we know the number of people exposed to a certain level of concentration. In the penultimate step, we want to calculate how many years of life lost/sick days/hospital admissions/etc. result from exposure to these concentration changes. This can be attained by plugging the concentration values (as found in the previous step) in the respective concentration response (CR) functions. An overview of these functions is given in Table ii, clustered per pollutant. The functions for PM10 and PM2.5 are designed to evaluate both primary and secondary particles. It is to say, both 'PM10 pr' and secondary pollutants <10µm (secondary inorganic aerosols = 'SIA') have to be assessed by the CR functions for PM10. Completely analogous can all the concentrations of ‘PM2.5 pr’ and SIA < 2.5µm be examined against the CR functions for PM2.5.

The actual concentration response function used can be found in the column ‘Relative Risk’ or ‘Impacts Function’. These are the two possible methods used to calculate health impacts. Wherever feasible, we use the relative risk numbers because these can be related to particular Belgian incidence numbers (assuming that Flemish incidence percentages are also valid for the Belgian population). This method is perfectly defensible, as most of the health externalities from Belgian transport will burden Belgian citizens. The impact function approach, on the other hand, applies general European incidence numbers for its impact calculation. We only use this approach when we do not dispose of a relative risk number.

After that, the actual impact calculation for each grid cell in the hot spot consists of the computation of a number of attributable cases in one year, and this for each disease mentioned in Table ii. The next section explains how each unit of these health points is further monetized.

Effect	Pollutant	Age Group	Relative Risk	Impact Function	Unit / Explanation	Source
New cases of chronic bronchitis	PM10	27+	1.07	N.A.	7% attributable cases in age group per 10 µg/m3	CAFE (2005a)
Infant mortality	PM10	1 mo-1 yr	1.04	N.A.	4% attributable cases in age group per 10 µg/m3	ExternE (2005)
Respiratory hospital admissions	PM10	all	1.011	N.A.	1.1% attributable cases per 10 µg/m3	CAFE (2005a)
Cardiac hospital admissions	PM10	all	1.006	N.A.	0.6% attributable cases per 10 µg/m3	CAFE (2005a)
Bronchodilator use children	PM10	5-14 yr	1.005	N.A.	0.5% attributable cases in age group with asthma per 10 µg/m3	CAFE (2005a)
Bronchodilator use adults	PM10	20+	1.01	N.A.	1% attributable cases in age group with asthma per 10 µg/m3	CAFE (2005a)
Lower respiratory symptoms children	PM10	5-14 yr	N.A.	1.86	symptom days per year, per person in age group, per 10 µg/m3	NEEDS (2007a)
Lower respiratory symptoms adults	PM10	20+	N.A.	1.3	symptom days per year, per person in age group with chronic respiratory symptoms, per 10 µg/m3	NEEDS (2007a)
Adult mortality after chronic exposure	PM2.5	30+	N.A.	0.00651	years of life lost (YOLL) per person per 10 µg/m3, function for total population	NEEDS (2007a)
Restricted activity days	PM2.5	15-64 yr	N.A.	0.902	days per year, per person in age group, per 10 µg/m3	NEEDS (2007a)
Minor restricted activity days	PM2.5	18-64 yr	N.A.	0.577	days per year, per person in age group, per 10 µg/m3	NEEDS (2007a)
Work loss days	PM2.5	15-64 yr	1.046	N.A.	4.6% attributable cases in age group per 10 µg/m3	ExternE (2005)
Adult mortality	ozone	all	1.003	N.A.	0.3% attributable cases per 10 µg/m3	ExternE (2005)
Minor restricted activity days	ozone	18-64 yr	N.A.	0.115	days per year, per person in age group, per 10 µg/m3	NEEDS (2007a)
Respiratory hospital admissions	ozone	65+	1.005	N.A.	0.5% attributable cases in age group per 10 µg/m3	ExternE (2005)
Bronchodilator use	ozone	20+	1.006	N.A.	0.6% attributable cases in age group with asthma per 10 µg/m3	CAFE (2005a)
Cough days	ozone	5-14 yr	0	0.93	days per year, per person in age group, per 10 µg/m3	NEEDS (2007a)
Lower respiratory (excl cough) symptoms	ozone	5-14 yr	0	0.16	days per year, per person in age group, per 10 µg/m3	NEEDS (2007a)

Table ii: Concentration reponse functions used for the calculation of health impacts

Please note that the effects originating from PM2.5 can be added to those from PM10, as the concentration response functions are designed in such a way that double countings are avoided. It is to say, concentrations of PM2.5 are always a subset of total PM10 concentrations (i.e., all particles with an aerodynamic diameter lower than 10 µm). The general class of PM10 concentrations are evaluated by using ‘PM10 concentration response funtions’. However, the finer particles of PM10 (i.e., PM2.5) are considered being more harmful than the more coarse fraction (particles between 2.5 and 10 µm). Consequently, concentrations of PM2.5 are additionally valued by separate functions.

It should now be clear that the fraction between 0 and 2.5 µm is valued twice. First of all, they are included in the general PM10 concentration response functions. Secondly, these particles receive an extra external cost following the functions for PM2.5. The fraction between 2.5 and 10 µm, on the other hand, is only valued through the general PM10 functions.

3.1.5 Monetization

The final step is then the monetization, i.e. the monetary valuation of the end points decribed in the previous step.

We can attach a certain amount of money to one incidence of each of the 18 health end points listed in Table ii. Therefore, we use the numbers from willingness-to-pay (WTP) studies, as listed in the NEEDS (2006) project, and recently actualized in NEEDS (2009) and the recommendations by Franckx et al. (2009). Subsequently, where necessary we convert these amounts (in $Euro_{2000}$ terms) to $Euro_{2009}$ terms, by using the aggregated inflationary pressure between 2000 and 2009. However, the overall increase of real income is not incorporated in these numbers. This feature can be added in the PLANET module. The result of the monetization is given in Table iii.

Effect	Pollutant	WTP/unit (Euro2009)	Unit
New cases of chronic bronchitis	PM10	119,291	case
Infant mortality	PM10	66,569	YOLL
Respiratory hospital admissions	PM10	4,856	case
Cardiac hospital admissions	PM10	5,776	case
Bronchodilator use children	PM10	0.31	case
Bronchodilator use adults	PM10	0.31	case
Lower respiratory symptoms children	PM10	55	day
Lower respiratory symptoms adults	PM10	55	day
Adult mortality after chronic exposure	PM2.5	44,379	YOLL
Restricted activity days	PM2.5	78	day
Minor restricted activity days	PM2.5	51	day
Work loss days	PM2.5	123	day
Adult mortality	ozone	66,569	YOLL
Minor restricted activity days	ozone	51	day
Respiratory hospital admissions	ozone	4,856	case
Bronchodilator use	ozone	0.31	case
Cough days	ozone	55	day
Lower respiratory (excl cough) symptoms	ozone	55	day

Table iii: Monetary valuation for each health end point

The column 'WTP/unit' represents the monetary valuation for each unit of the health point, with the unit measure explained in the column 'Unit'. For example, PM10 exposure resulting in a respiratory hospital admission is valued at 4,856 euro, whereas each year of life lost (YOLL) from an acute child death is valued at 66,569 euro, and each time a bronchodilator is used is valued at 0.31 euro.

Next, the number of attributable cases from the previous step (impact calculation) can be multiplied by its monetary unit valuation from the current step. This is done for all grid cells in the hot spot. We decided to cluster the results by concentration pollutant, such that we find external costs from an emission of PM2.5 or NO_x acting through concentrations of primary PM10 ('PM10 pr'), primary PM2.5 ('PM2.5 pr'), sulphate aerosols ('sulph 2.5'), nitrate aerosols ('nitr 2.5') and ozone (O_3).

Each of the differentiating scenarios is then compared with the BAU scenario, i.e. for each grid cell we compute the external costs both for the differentiating scenario and for the BAU scenario. Consequently, the difference between these two is the change in external costs. The only task left is to divide this external cost difference by the initial marginal emission change (20% transport emissions for either PM2.5 or NO_x) in order to calculate the marginal external cost (per tonne of emission, if desirable split per concentration pollutant) resulting from each differentiating scenario. The results for PM2.5 and NO_x are discussed below.

→ ***The external cost per tonne of transport-related PM2.5***

The results for PM2.5 can be summarized as follows (see Figure N and Figure O).

The external cost per tonne of transport-related PM2.5 emissions ranges from 107 kEUR (2007) to 115 kEUR (2030). For 2020, the result is somewhere in between (112 kEUR). The increasing trend can be attributed completely to the projected demographic evolution, as will be discussed further in this report. The resulting numbers are plausible in the light of the ExternE results found by Friedrich & Bickel (2001): they report 74 kEUR/tonne without taking into account the Diesel Motor Emissions. They are all the more confirmed by the numbers published in IMPACT (2008). In the paragraph below, we explain why.

The IMPACT (2008) study reports marginal external costs per tonne of Belgian emissions for metropolitan, urban and outside built-up areas as being 422 kEUR, 136 kEUR and 91 kEUR, respectively. These numbers take into account emissions for road, rail and waterways. We can now try to compute the average, weighted for the distances driven on each of these road types. From the FOD Mobiliteit (2008), we know that 36.44%, 22.72% and 40.84% of all vehicle kilometres are driven respectively on highways, urban roads and other roads. However, in order to construct the same road classes for both cases, we assume that the sum of all distances driven on 'highways' and 'other roads' is equal to the distance driven in the 'outside built-up' class in IMPACT (2008). We further suppose that the 'urban roads' from FOD Mobiliteit (2008) correspond to the sum of the 'urban' and 'metropolitan' class in IMPACT (2008). The ratio of distances driven in metropolitan areas versus distances driven on all kinds of urban roads is assumed to be 7.29%. We found this number by taking 1.5 times the ratio of total urban kilometers driven in Brussels, divided by total Belgian urban kilometers, because Brussels and Antwerp are the only Belgian cities large enough to be considered as metropolitan (i.e. >0.5 million inhabitants) and assuming the urban distances driven in Antwerp are only half of those driven in Brussels. Taking all this into account leads to a weighted average MEC from PM2.5 of 106 kEUR/tonne (77.28%, 1.66% and 21.06% of the kilometers driven in outside built-up areas, on metropolitan and urban roads, respectively). This is indeed very close to our own computation for PM2.5 health effects.

Externalities occurring through the fraction of PM2.5 without secondary aerosols ('PM2.5 pr', i.e. primary PM2.5), constitute the largest share of the per tonne cost. All the concentration pollutants have a positive sign, except the nitrate fraction. These values are too small however, to be considered as an important external benefit.

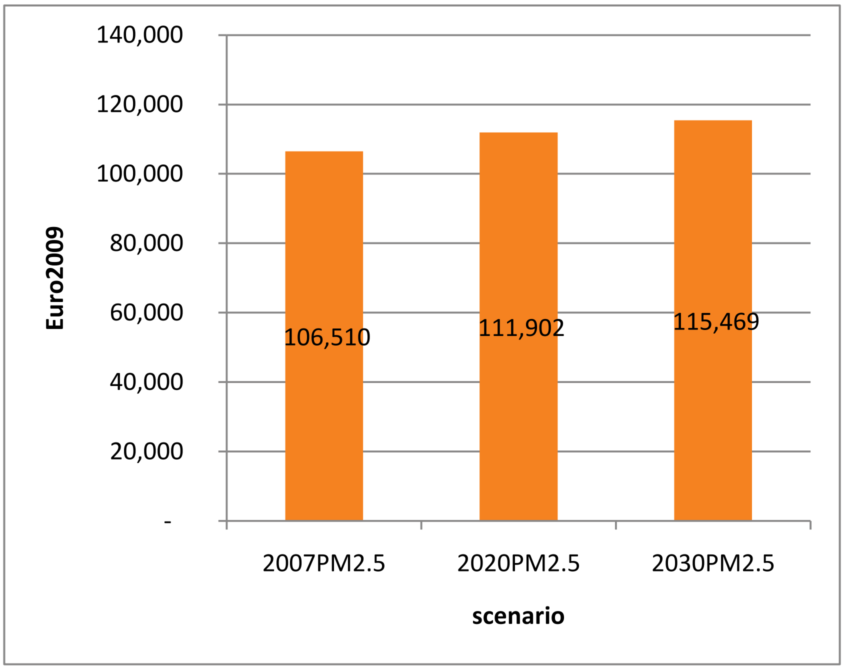
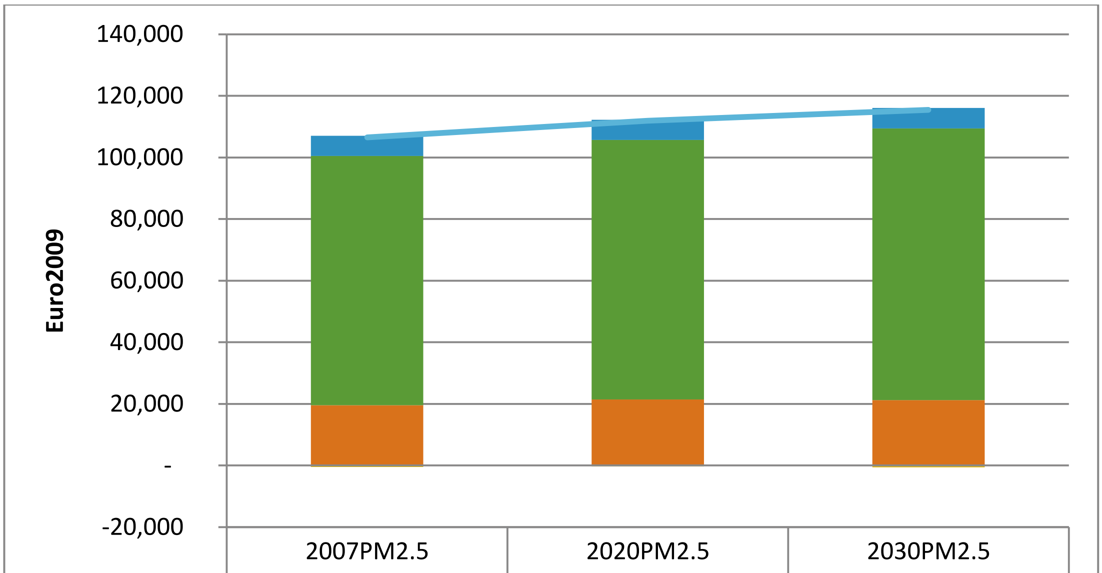


Figure N: External costs per tonne of PM2.5 (Belgium)



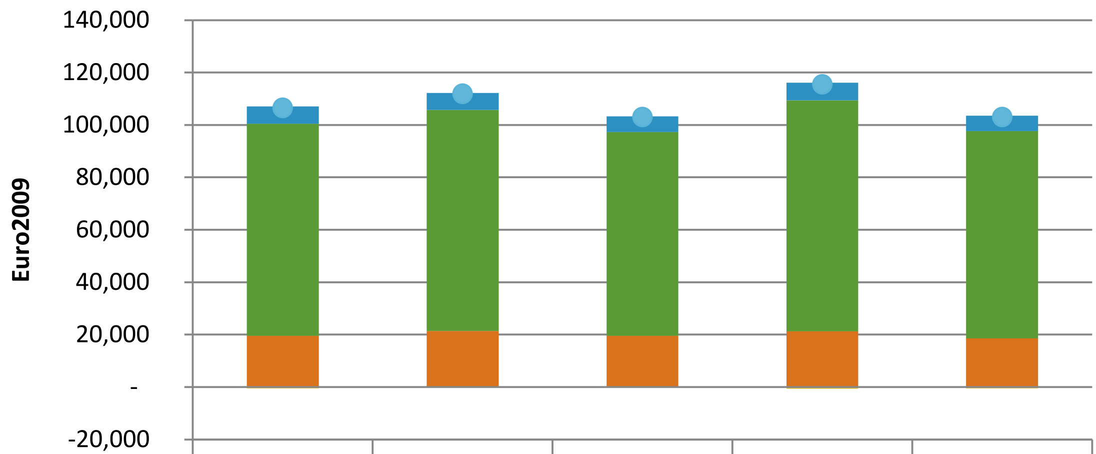
	2007PM2.5	2020PM2.5	2030PM2.5
O3	-	-	-
nitr 2.5	-552	-297	-583
sulph 2.5	6,601	6,508	6,616
PM2.5 pr	80,899	84,264	88,237
PM10 pr	19,563	21,427	21,200
TOTAL	106,510	111,902	115,469

scenario

Figure O: External costs per tonne of PM2.5 split by source (emitted in Belgium)

The population growth and changes in age distribution are impacting the marginal external costs as well. This impact is already included in Figure N and Figure O. It is useful to separate the population growth impact from the 'genuine' concentration impact. This is done in Figure P, where the only particularity for the scenarios with the suffix '_2007' is that they are run with population numbers from the year 2007. For example, the scenario '2020PM2.5_2007' is the 2020PM2.5 scenario with population from 2007 instead of 2020. The difference between each of the two scenarios is then the impact of demographic evolution (since 2007) on marginal external costs.

Marginal external costs from the scenario 2020PM2.5_2007 are ca. 8.9 kEUR lower than in the original scenario, i.e. 8% of total costs in 2020 can be attributed to population growth. Costs for 2030PM2.5_2007 are ca. 12.4 kEUR lower than in its original scenario. This means that 11% of total impacts in 2030 can be attributed to a change in population since 2007. This also implies that without the projected population growth, the marginal external costs from PM2.5 are relatively flat over time.



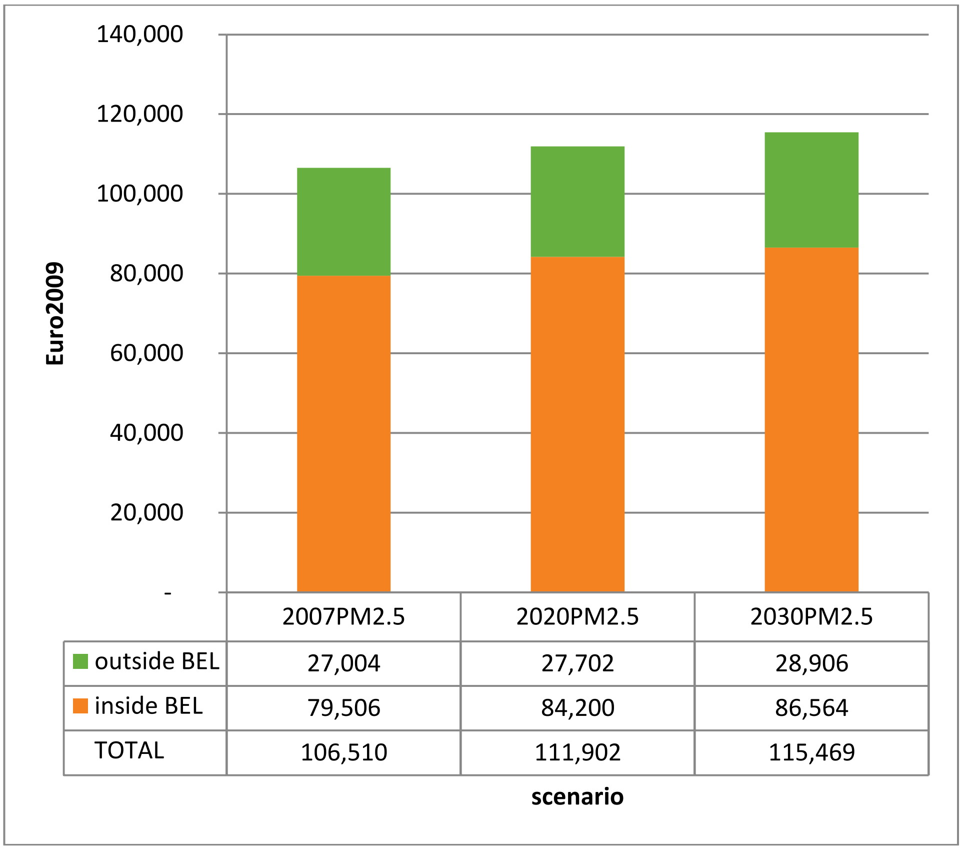
	2007PM2.5	2020PM2.5	2020PM2.5_ 2007	2030PM2.5	2030PM2.5_ 2007
O3	-	-	-	-	-
nitr 2.5	-552	-297	-273	-583	-520
sulph 2.5	6,601	6,508	5,991	6,616	5,903
PM2.5 pr	80,899	84,264	77,765	88,237	79,028
PM10 pr	19,563	21,427	19,523	21,200	18,625
TOTAL	106,510	111,902	103,006	115,469	103,036

scenario

Figure P: Population growth impacts on external costs per tonne of PM2.5 (emitted in Belgium)

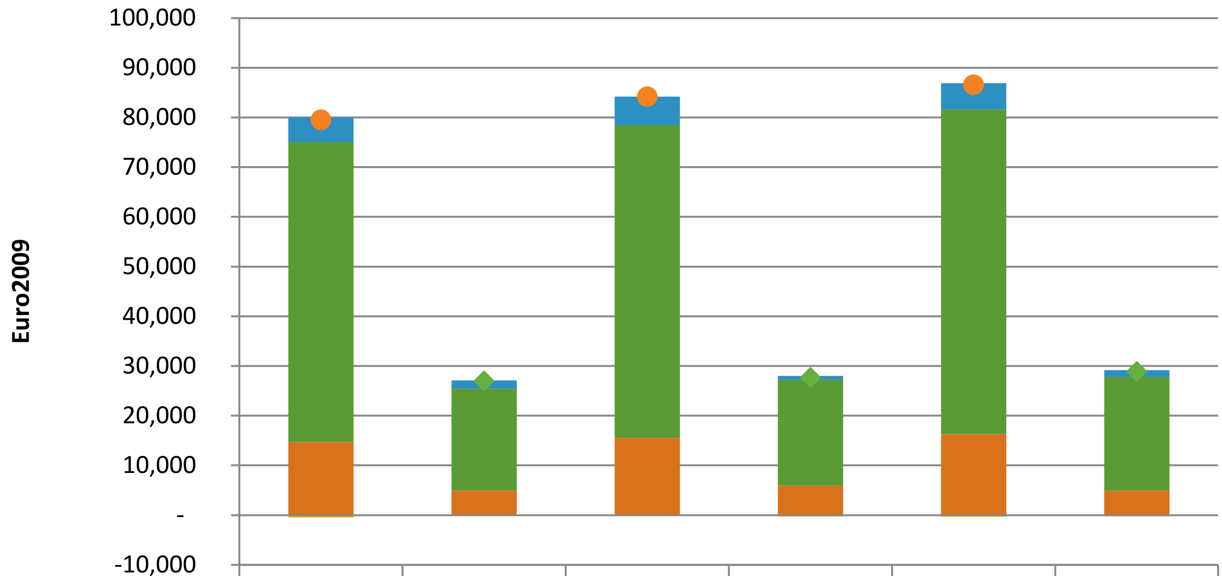
It is interesting to distinguish between the impacts of Belgian PM2.5 emissions on the Belgian territory on the one hand and impacts occurring beyond the Belgian borders, on the other. This is done in Figure Q. For all scenario years, the impacts found outside Belgium amount to about 25% of total MEC. Please note that not all effects on foreign areas are included, as we arbitrarily chose our model grid relatively close around Belgium. Consequently, we recognize that we will miss (a small) part of the marginal external costs taking place abroad.

In Figure R, these effects are disaggregated over the different concentration classes. The relative shares of these categories in total costs are not explicitly different for Belgian costs compared to the costs occurring abroad.



	2007PM2.5	2020PM2.5	2030PM2.5
outside BEL	27,004	27,702	28,906
inside BEL	79,506	84,200	86,564
TOTAL	106,510	111,902	115,469

Figure Q: External costs per tonne of PM2.5, occurring inside and outside Belgium



	2007PM2.5 inside BEL	2007PM2.5 outside BEL	2020PM2.5 inside BEL	2020PM2.5 outside BEL	2030PM2.5 inside BEL	2030PM2.5 outside BEL
O3	-	-	-	-	-	-
nitr 2.5	-468	-84	-14	-283	-341	-241
sulph 2.5	4,932	1,669	5,768	741	5,293	1,323
PM2.5 pr	60,404	20,495	62,929	21,335	65,348	22,888
PM10 pr	14,639	4,924	15,517	5,909	16,264	4,935
Total inside BEL	79,506	-	84,200	-	86,564	-
Total outside BEL	-	27,004	-	27,702	-	28,906

scenario

Figure R: External costs per tonne of PM2.5 (split), occurring inside & outside Belgium

→ ***The external cost per tonne of transport-related NO_x***

For NO_x, the external cost per tonne of emission is about 2.5 kEUR 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. See Figure S and Figure T.

It seems that in 2007, the marginal external benefit from ozone and sulphate aerosols completely outweighs the marginal external cost originating from the formation of nitrate aerosols. For the years 2020 and 2030, the image is somewhat different. Sulphate aerosols and ozone still constitute a marginal external benefit. However, they are not large enough to compensate for the increased marginal external cost of nitrate aerosols.

These results are more or less in line with MIRA (2010), which is the only available study where similar detailed calculations for emissions of NO_x were performed. The comparable data amount to -5.3 kEUR and +4.0 kEUR, for emissions in 2007 and 2020 respectively (also in $Euro_{2009}$). However, it should be kept in mind that the methodology used in MIRA (2010) differs from the one used here in three aspects. First of all, a MEC for Flemish emissions is not the same as a MEC for emissions in Belgium, 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.

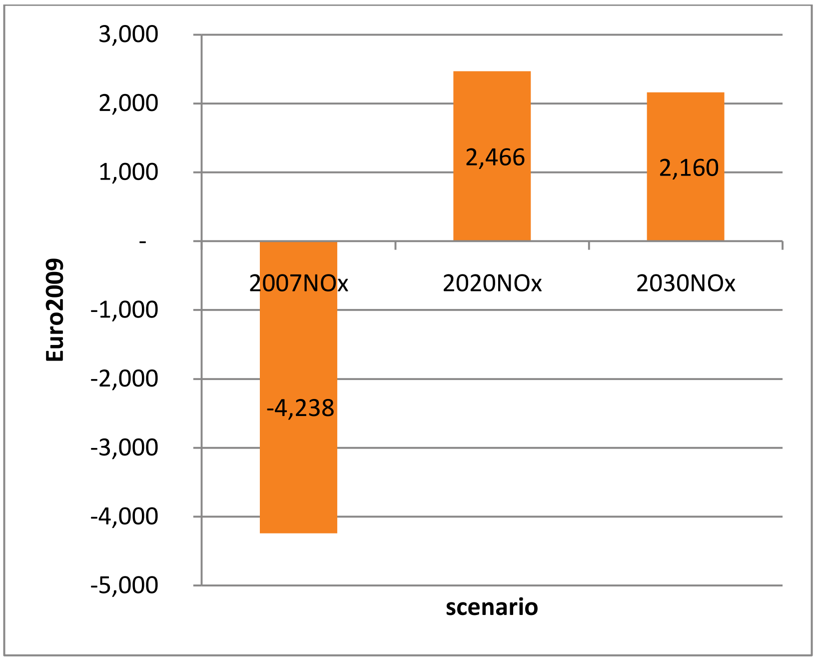
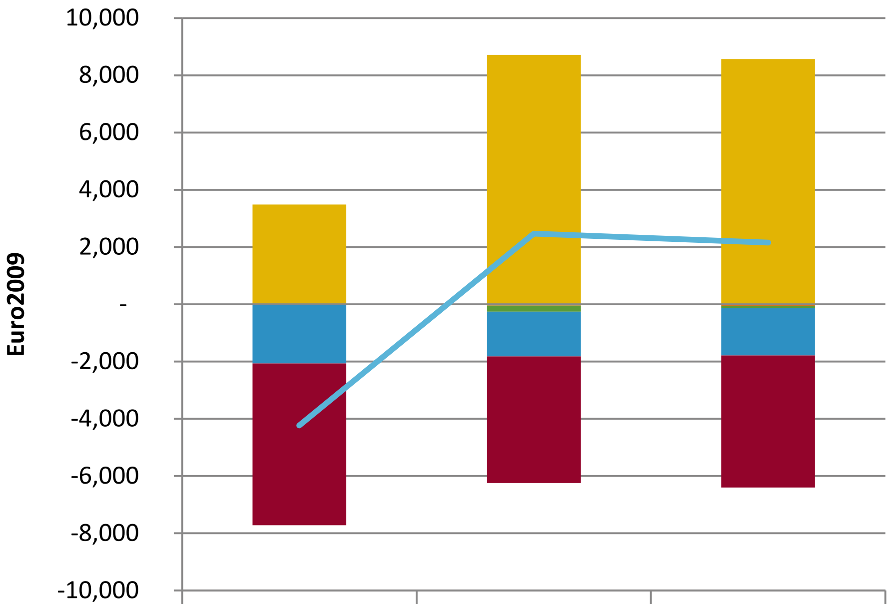


Figure S: External costs per tonne of NO_x (emitted in Belgium)



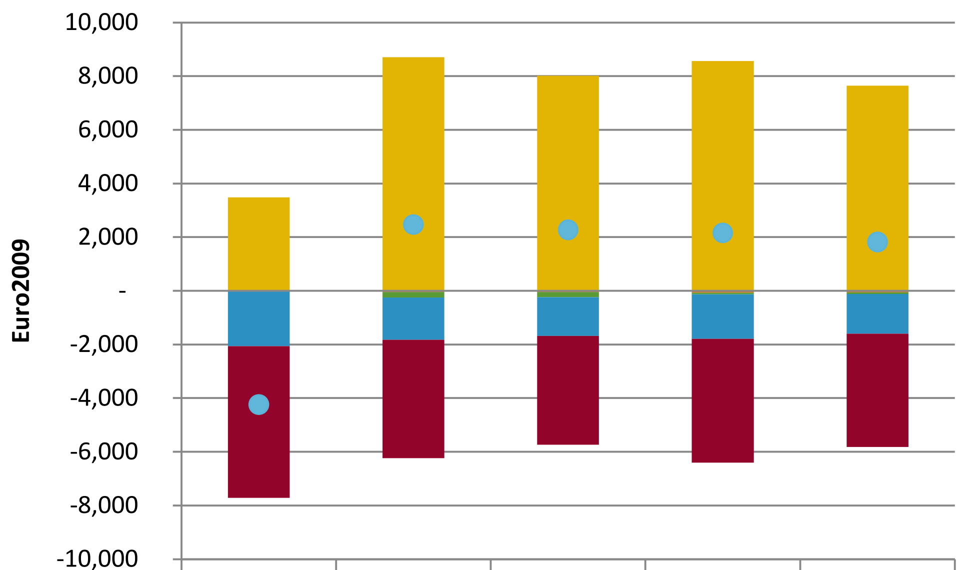
	2007NOx	2020NOx	2030NOx
O3	-5,655	-4,416	-4,610
nitr 2.5	3,472	8,707	8,562
sulph 2.5	-2,055	-1,573	-1,658
PM2.5 pr	11	-206	-65
PM10 pr	-10	-48	-69
TOTAL	-4,238	2,466	2,160

scenario

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

We can again deduce the population impacts from these numbers, as depicted in Figure U. When population numbers from 2007 are used for 2020 and 2030, we notice again a decline in the absolute values of the original marginal externalities. For 2020, the impact from the population changes since 2007 on the marginal external cost is 192 EUR, i.e. 8% of the original value. The impact in scenario year 2030 amounts to 16% (339 EUR).

Figure V summarizes the separated population impacts since 2007, expressed as a percentage of the total marginal external cost.



	2007NOx	2020NOx	2020NOx_ 2007	2030NOx	2030NOx_ 2007
O3	-5,655	-4,416	-4,061	-4,610	-4,221
nitr 2.5	3,472	8,707	8,016	8,562	7,639
sulph 2.5	-2,055	-1,573	-1,448	-1,658	-1,479
PM2.5 pr	11	-206	-190	-65	-58
PM10 pr	-10	-48	-43	-69	-61
TOTAL	-4,238	2,466	2,274	2,160	1,821

scenario

Figure U: Population growth impacts on external costs per tonne of NO_x emitted in Belgium

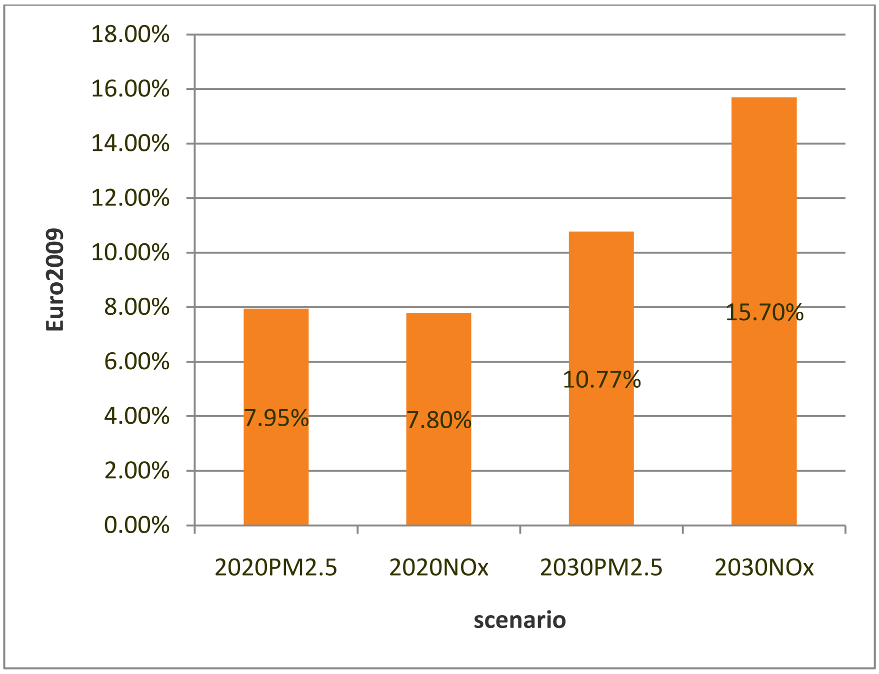
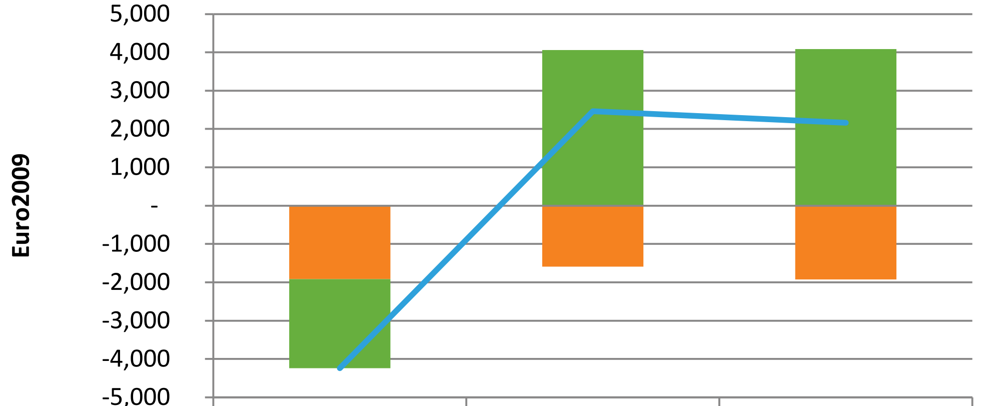


Figure V: Impact from demographical change since 2007

Just like we did earlier for PM2.5, we can now also look at the geographical split of marginal externalities from NO_x.

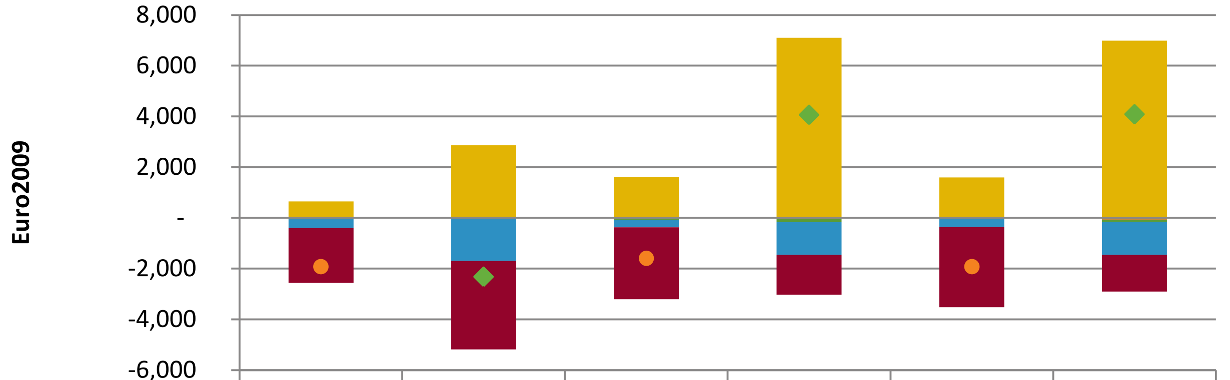
Figure W shows that marginal external costs from NO_x, occurring inside Belgium, are negative for all scenario years. This domestic marginal external benefit is further expanded by the foreign effects in 2007, whereas it is more than compensated for in the scenario years 2020 and 2030.

In Figure X, these effects are again split up over the five concentration classes. It is noteable that (the absolute value of) marginal costs from nitrate and sulphate aerosols are 3 to 5 times higher for foreign areas than for domestic areas. Furthermore, the foreign ozone effect is higher than its domestic counterpart for 2007, which is no longer the case for the years 2020 and 2030.



	2007NOx	2020NOx	2030NOx
outside BEL	-2,319	4,060	4,084
inside BEL	-1,919	-1,594	-1,924
TOTAL	-4,238	2,466	2,160

Figure W : External costs per tonne of NO_x, occurring inside and outside Belgium



	2007NOx inside BEL	2007NOx outside BEL	2020NOx inside BEL	2020NOx outside BEL	2030NOx inside BEL	2030NOx outside BEL
O3	-2,164	-3,491	-2,833	-1,583	-3,158	-1,452
nitr 2.5	642	2,829	1,613	7,095	1,575	6,987
sulph 2.5	-361	-1,694	-289	-1,284	-361	-1,297
PM2.5 pr	-29	40	-70	-135	18	-83
PM10 pr	-7	-3	-15	-33	2	-71
Total inside BEL	-1,919	-	-1,594	-	-1,924	-
Total outside BEL	-	-2,319	-	4,060	-	4,084

Figure X: External costs per tonne of NO_x (split), occurring inside and outside Belgium

3.1.6 Discussion on the impact from NO_x emissions

Compared to the impacts from PM2.5, the marginal external costs arising from NO_x emissions are rather small. This is due to the different kind of effects resulting from both emission classes. Emissions of PM2.5 result in very high absolute values of primary PM2.5 concentrations. Moreover, these particles cause the highest health impact of all the substances included in this study. Emissions of NO_x, however, mainly act through concentrations of nitrate aerosols, which could offset the marginal external benefit from the lowered concentrations of ozone and sulphate aerosols. In this paragraph, we explain the marginal external benefit through lowered ozone and sulphate aerosol concentrations.

The theoretical formation of ozone is dependent on some chemical reactions (Schwartz, 2006). NO_x consists of molecules of NO and NO_2. These two molecules react with oxygen to form ozone following the reactions below:

(1) $NO_2 + \text{sunlight} \rightarrow NO + O$

(2) $O + O_2 \rightarrow O_3$

(3) $O_3 + NO \rightarrow O_2 + NO_2$

The result of this cycle is a low level of ozone formation. It is to say, where ozone is formed in reaction (2), it is destroyed in reaction (3).

The presence of VOC can change this, as it will allow reaction (3) to be bypassed, by regenerating NO_2 from NO without the destruction of ozone. Some VOC is converted by OH radicals to form peroxy radicals (-OO) which can then react with NO, as follows:

(4) $VOC\text{-}OO + NO \rightarrow NO_2 + VOC\text{-}O$

NO is now reacting with the peroxy radical instead of the ozone molecule, resulting in more ozone remaining from reaction (2) and more NO_2 being available which can form new ozone molecules.

We can now understand why the level of ozone formation depends on the VOC/NO_x ratio.

Indeed, when VOC/NO_x is high, NO_x will be the limiting factor. Consequently, reaction (4) is dominant over reaction (3) for the regeneration of NO_2. Lowering emissions of NO_x will directly result in lower ozone levels, as less NO_2 will be available to generate ozone via reactions (1) and (2). Decreasing VOC will have no (or a very limited) impact on ozone creation.

With low VOC/NO_x ratios, the cycle changes towards a dominance of reaction (3) over (4), because of the limited VOC concentration. Reducing VOC emissions will now result in a reduction of ozone, as less NO_2 is formed. Moreover, lowering NO_x emissions will lead to higher levels of ozone. This can be attributed to two facts. First of all, less NO is available in reaction (3) to break down ozone. Secondly, NO_2 regeneration is sped up by reaction (4), which results in a faster formation of ozone per molecule of NO_x.

Applying these relations to the Belgian case, we know we have to deal with a low VOC/NO_x ratio (Deutsch et al., 2009). The formation of ozone is thus determined by the concentration of VOC. Following this abundance of NO_x (with NO as its major component), ozone is broken down during the majority of the year, while ozone is usually only formed during a few sunny summer days. The process of ozone decomposition through NO is thus the dominant process in Belgium. And it is partly thanks to NO_x emissions from traffic sources that we still have some northern hemispheric ozone (i.e., the background ozone concentrations) broken down. This explains the marginal external benefits from NO_x emissions through ozone.

In future years, it is expected that NO_x emissions will continue to fall. Less NO_x emitted results in less NO available and thus a smaller amount of ozone broken down. This aspect will not influence the marginal external cost, as this is measured on a fixed per tonne base. A second aspect is that the increasing use of modern vehicle engines causes the share of NO in NO_x emissions to fall, while the share of NO_2 will rise. Thus, each tonne of NO_x emitted in 2020 or 2030 has a smaller potential of ozone reduction than a tonne emitted in 2007. Consequently, less NO is left to destroy ozone, whereas more NO_2 remains available to form secondary nitrate aerosols (purple bar in Figure T).

In a policy context, these relationships imply that we will need substantial decreases in concentrations of NO_x in order to reach the other side of the ozone peak. I.e., only with a higher VOC/NO_x ratio there is a chance of being able to lower ozone concentrations through NO_x abatement.

The marginal external benefit from emissions of sulphate aerosols is then quite obvious. It is to say, the marginal increase of NO_x emissions causes a rise in the absolute amount of ammonium nitrate being formed, as the NO molecules bind with oxygen. This results in less ammonia groups being available for the sulphate fractions in order to form the aerosol ammonium sulphate (lowered concentration). Consequently, marginal external costs from NO_x acting through sulphate aerosols are negative, i.e. a marginal external benefit.

3.1.7 Marginal external costs from other pollutants

In the previous paragraphs, we exclusively focused on the human health effects of NO_x and PM2.5. We made this decision because of the importance of these two pollutant classes and the budget constraints from the project. For the other pollutants originating from transport, we adopt marginal external cost numbers as described in some large influential European studies. The results of a recent MIRA study are also included. For transport, it is useful to additionally look at the effects of PM10, SO_2 and NMVOC.

IMPACT (2008) integrates most of the results given in the European research frameworks concerning external costs. We already mentioned the results for PM2.5 when comparing with our own methodology. We found there that our own results are broadly in line with the numbers listed in IMPACT (2008). So, for the other pollutants, we may come close if we just import the Belgian numbers from IMPACT (2008), taking into account that each of the underlying studies may make slightly different assumptions.

→ ***PM10***

We know that PM10 emissions from transport are originating both from exhaust and non-exhaust sources, as they comprise particles smaller than 2.5µm and particles with a size between 2.5 and 10µm (i.e. PMcoarse). According to IMPACT (2008), which refers to HEATCO (2006), the marginal external cost amounts to 169.9, 54.5 and 36.5 $kEUR_{2000}$ for metropolitan, urban and outside built-up areas, respectively. This leads to an average of 43 $kEUR_{2000}$/tonne or 52 kEUR/tonne PM10 in $Euro_{2009}$ terms, when using the distribution over the road segments given earlier. This number contrasts with the 122 $kEUR_{2009}$/tonne found in MIRA (2010), for Flemish low source emissions in 2007. This difference can be attributed to the fact that MIRA (2010) assumes a different share of PM2.5 emissions in total PM10, that it models emissions more accurately, and that it looks at Flemish instead of Belgian emissions. However, it has to be mentioned that it is better to use separate marginal external cost figures for PM2.5 and PMcoarse, rather than combine these in one figure for PM10. This is because the share of PM2.5 in PM10 may vary across scenarios. Therefore, we propose to use the marginal external cost of **24 $kEUR_{2009}$/tonne** for **PMcoarse** from low sources (27$kEUR_{2009}$/t for emissions in 2020, due to population growth and evolution over the age classes). It has to be mentioned that MIRA value is the result of the combined emissions from road traffic and the residential sector. The fact that the residential sector is included here could be an explanation for the relatively low value, as emissions from houses mainly take place at greater height than tailpipe emissions do. Further research is necessary to shed more light on this.

→ ***SO_2***

IMPACT (2008) mentions an external cost of 11 kEUR/tonne for SO_2 emissions from transport (i.e. 14 kEUR/tonne in $Euro_{2009}$ terms). This number is extracted from CAFE (2005b), from which the lower bound is used. This lower limit corresponds to the median VOLY, i.e. the value of a life year (50 kEUR), from NewExt (2003) in order to value the impacts from PM2.5 and ozone. This contrasts with NEEDS (2006), in which the authors suggest 40 kEUR for a VOLY in EU25. The latter value is more in line with our own methodology for NO_x and PM2.5 (see Table i). Another difference compared to our own methodology is the inclusion of crop effects, besides the core health functions. The so-called 'lower limit' from CAFE (2005b) should thus logically result in slightly higher values than our own methodology, all other things remaining the same. According to the results from MIRA (2010), **SO_2** emitted by low sources in 2007 brings about a marginal external cost of ca. **7 $kEUR_{2009}$/tonne** (9 $kEUR_{2009}$/t for emissions in 2020), if we consider exactly the same impacted grid as we did for Limobel. For this pollutant, the inclusion of residential emissions is no drawback, as the figure seems to be independent of the height of the emissions.

→ ***NMVOC***

IMPACT further suggests a value of 2.5 kEUR/tonne (or 3 $kEUR_{2009}$/tonne) for transport emissions of **NMVOCs**. This value is also taken from the lower bound in CAFE (2005b).

Obviously, the same remarks apply as given for SO_2. MIRA (2010), on the other hand, suggests a marginal external cost of **6.5 $kEUR_{2009}$/tonne** (both for emissions in 2007 and 2020). The large difference compared to IMPACT (2008) can be due to the very detailed modelling of ozone formation in the BelEUROS model. We expect the detailed Flemish study to be more representative for emissions in Belgium than a broad European study like IMPACT.

3.2 Impact of air pollution on building degradation and soiling

Besides human health impacts from air pollution, there are other categories that should be highlighted in order to have a clear image on external environmental costs from transport. Concerning impacts from air pollution, we additionally discuss the impacts on building materials. Damages on ecosystems are not calculated in this report, because of the lack of reliable concentration-response indicators in the literature. Impacts on agricultural crops are neglected as well, as background pollution will change sharply in the future and the impact from transport on crops can be assumed to be very limited. Two other important categories of transport EECs, i.e. impacts from climate change and noise, are discussed in the next chapters.

Damage to building materials can be classified into two groups, i.e. building degradation (corrosion) and soiling. Basic methodologies are described in New Ext (2003), ExternE (2005) and NEEDS (2007b). Degradation mainly takes place through the interaction of SO_2 in combination with other gaseous pollutants (ExternE, 2005), from which corrosion could occur. Soiling takes place when a surface of a material gets darker as a result of the deposition of carbon particles. Soiling can be measured by a change in light reflectance, as soiled material gets darker (ExternE, 2005).

Concerning **building degradation (corrosion)**, we refer to Holland & Watkiss (2002). The calculation of this damage is a difficult task as it has to take into account pollutant concentrations and deposition, but also meteorological data. Therefore, the authors alternatively used the high correlation between material damages and health damages from SO_2 emissions in order to estimate material degradation per tonne of SO_2 emitted. For Belgium, they find a corrosion damage of 367 EUR_{2002}/tonne of SO_2 emission, or 430 EUR_{2009}/tonne SO_2. It is useful to look at the other numbers reported in literature. The more recent CASES project (2008) found a marginal external cost of 453 EUR_{2000}/tonne SO_2, i.e. 558 EUR_{2009}/tonne. This is also the value suggested by the authors of MIRA (2010). Torfs et al. (2005), on the other hand, find an external cost of 375 EUR_{2005}/tonne, which equals 418 EUR in 2009 terms. As the three resulting numbers are all in the same range (418-558 EUR_{2009}/tonne), we decide to do further calculations with their arithmetic mean, i.e. **469 EUR_{2009}/tonne SO_2**. We assume that this figure remains unchanged for emissions in the future.

The other external cost related to material damage is **building soiling**. Emissions of PM are mainly responsible for the darkening of building surfaces. It is difficult to find reliable indicators for this class of externalities. In particular, we do not find any marginal external cost figure (per tonne of emission) for this impact category. Although the CLEVER (2009) report displays interesting figures on soiling costs per vehicle kilometer, we decide not to take vehicle soiling costs into account, as the levels of uncertainty are currently too high.

3.3 Summary

As a summary, the table below gives an overview of the marginal external cost figures mentioned in chapter 3 on air pollution. All figures are displayed in $Euro_{2009}$ terms, without taking into account a possible increase in real income.

	Marginal EC [EUR/tonne]			
Emitted Pollutant	**2007**	**2020**	**2030**	**Source**
PM2.5	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)

Table iv: Marginal external cost figures from air pollution

CHAPTER 4 MARGINAL EXTERNAL ENVIRONMENTAL COST OF CLIMATE CHANGE

The most important greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). On a purely molecular base, CH_4 and N_2O are greenhouse gases with a larger global warming potential than CO_2. However, CO_2 is the most abundant in the atmosphere and is the largest contributor overall. Therefore, we focus on CO_2 equivalents (CO_2eq) instead of the separate gases. The remainder of this chapter describes a set of marginal external cost figures for CO_2 equivalents.

In order to value each tonne of CO_2eq emitted by transport in Belgium, there are two possible approaches. Either one can work with damage costs, or with avoidance costs. In the damage cost approach, which is based on the impact pathway approach, one calculates the physical and economical damages resulting from climate change. Damage costs are rather difficult to calculate and there exists large disagreement in literature about which cost classes to include. Some suggestions can be found in Tol (2005) and Stern (2006). The avoidance cost approach uses the minimal cost to reach a certain emission reduction target. This approach is more practical and moreover, it has a link with real-life policy targets.

In IMPACT (2008), emissions for the short term (2010 and 2020) are valued based on avoidance costs, because policy targets are already available for this period and uncertainty is lower for this approach. For the longer term (2030 and later), the recommended values are based on the damage cost approach, because this method is more consistent with other external cost valuations. Another reason is the lack of agreed policy targets for those years. The recommended marginal external costs are displayed in Table v, which is already converted to $Euro_{2009}$ values (multiplied by the inflation growth factor in 2008). For each year, we now dispose of a central value with an upper and lower limit. We compare these numbers with a value of 50 EUR_{2009}/tonne, as assumed in MIRA (2008).

Cost per tonne CO_2eq (in $Euro_{2009}$)	2010	2020	2030
lower	7	18	23
central	26	42	57
upper	47	73	105

Table v: Marginal external cost for emissions of CO_2eq (adapted from IMPACT, 2008)

CHAPTER 5 EXTERNAL ENVIRONMENTAL COST OF NOISE

Damages from noise are not always easy to monetize. One can take either noise annoyance or the exposure to noise as a criterion for further calculations. In this report, we opt for the second approach. This gives us the opportunity to do calculations with the number of people exposed to certain noise levels, instead of dealing with the more complicated annoyance numbers.

An important indicator for noise damage is the Noise Sensitivity Depreciation Index (NSDI). This index displays the change (increase/decrease) in property prices when the noise level (measured in dB, L_{den} (i.e., weighted for day, evening, night)) changes (decrease/increase) by one dB. It is advisable to define a certain level of dB below which we assume no noise exposure at all. We choose to follow the approach defined in Navrud (2002). For road and air transport, the cutoff point is fixed at 55 dB, whereas rail transport receives a cutoff of 60 dB. This is due to the fact that railway noise from the same level is mostly perceived less disturbing than noise from the other modes. For all the noise levels above these thresholds, we could calculate the actual noise externality. This is preferably done by using a split NSDI, as the relative change in property price rises with higher noise backgrounds (Liekens et al., 2009). We could use a multi-level NSDI (Notteboom, 2006), see Table vi.

L_{den} (dB)	NSDI
55-60	0.4%
60-65	0.8%
65-70	0.9%
70-75	1.0%
>75	1.1%

Table vi: Multi-level NSDI (Notteboom, 2006)

The goal of this report is to provide an overview of marginal external cost numbers. Therefore, we decide not to elaborate the calculation of a total noise cost.

CHAPTER 6 MARGINAL ENVIRONMENTAL EXTERNAL COSTS OF MARITIME TRANSPORT

Belgian emissions from maritime transport can be categorized according to the location where they take place. Either a vessel moves in or between Belgian ports, or the movement takes place further seawards, on the continental shelf.

Concerning emissions in Belgian ports, we propose to use the marginal external cost values mentioned earlier in this report (human health and climate change).

For pollutants emitted on the continental shelf, we have to draw a distinction between impacts on human health and impacts on climate change. Impacts from those emissions on human health will be negligible in size, as the number of people affected comes close to zero (only shipping crew). Concerning impacts on climate change, the location of emission is no defining factor. Consequently, the greenhouse gas emissions from maritime transport can be evaluated using the figures presented in chapter 4.

In MIRA (2010), emissions from inland navigation are valued equivalently to emissions from transport on highways, as population densities in the immediate proximity are comparable. Therefore, we assume that emissions from activities on the Scheldt river can be treated in the same way. For emissions of PM2.5, we suggest to use the Flemish numbers found in MIRA (2010): 132 and 143 $kEUR_{2009}$/tonne, for emissions in 2007 and 2020 respectively. Concerning the other pollutants, we refer to the results from chapter three.

We are conscious of the fact that this is only an approximative approach. However, a more detailed analysis, with marginal external costs depending on the specific shipping route followed (as described by Sieber & Kummer, 2009), is far beyond the scope of this report.

CHAPTER 7 CONCLUSIONS

We discussed the most important environmental external cost categories from transport. Regarding marginal external costs of air pollution, we analysed impacts on human health and on buildings. External costs from climate change and noise were examined as well. The most important task was to obtain marginal figures for a set of pollutants. We did a very detailed analysis for human health impacts of PM2.5 and NO_x, whereas for the other pollutants and impact categories, we resorted to the literature.

The reason for doing our own calculations for PM2.5 and NO_x lies in the variation of the background concentrations. In other words, we wanted to predict how the external air pollution cost changes, following a variation in general air quality.

The marginal external cost calculation for human health impacts started from the notion that marginal cost figures can only be derived when both a baseline scenario and an alternative scenario is tested. The difference between these two scenarios is that the latter starts from a changed transport emission level of one particular pollutant. The result is a difference in external costs between the two scenarios. We divided this result by the emission difference in order to derive the marginal external cost of each pollutant. We followed this procedure for the major transport pollutants PM2.5 and NO_x. Concerning the other transport pollutants like SO_2, NMVOC and PM10, we determined our cost figures on the basis of the available literature.

Our analysis (for human health impacts from PM2.5 and NO_x) is based on the impact pathway method, as developed within the ExternE projects. In this approach, we started from Belgian emission data from our emission model E-motion, calculated concentration maps with the air quality model BelEUROS, took into account the exposed population, and used the result in the DALY-calculator model to find out how big the impacts and costs are.

The resulting external cost per tonne of transport-related PM2.5 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. The resulting numbers are plausible in the light of the ExternE results found by Friedrich & Bickel (2001) and the numbers published in IMPACT (2008). For NO_x though, the external cost per tonne of emission is about 2.5 and 2.2 kEUR for the years 2020 and 2030. However, for 2007 the model results in a marginal cost of -4.2 kEUR, i.e. a marginal external benefit.

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 marginal external cost figures described in this report 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 LTO cycle for air traffic. We executed our own scenario calculations for the years 2007 (as a proxy for the current situation), 2020 and 2030.

In our calculations, we took into account a Western European population growth rate which is based on the population outlook of the Belgian Federal Planning Bureau (FPB, 2009). We updated the impact calculation and monetization steps by using the most recent information on concentration-response functions and willingness-to-pay values from European projects as ExternE (2005), CAFE (2005a) and NEEDS (2006,2007a,2009), with updates for the specific Belgian case (Franckx et al., 2009).

In a recent study (MIRA, 2010), we estimated marginal external cost figures as well, for emissions in Flanders instead of Belgium. We suggested to use the numbers presented in that report for the evaluation of emissions other than PM2.5 and NO_x.

The result of this report is a table with marginal external cost figures for a set of pollutants, in $Euro_{2009}$ terms. However, the evolution of the future real income is not accounted for. It should be mentioned that only marginal impacts on human health are included, except for SO_2, where a marginal cost of 469 EUR/tonne for material corrosion is accounted for as well.

	Marginal EC [EUR/tonne]			
Emitted Pollutant	**2007**	**2020**	**2030**	**Source**
PM2.5	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	

Further research is needed to make a distinction for emissions originating from different road types. A first attempt is done in MIRA (2010) for Flemish emissions, with the help of the high resolution IFDM-RIO model.

An additional effort will be needed to elucidate the relationship between emissions of NO_x and the formation/degradation of ozone and secondary aerosols, now and in the future. The uncertainty regarding the relative importance between effects from ozone and secondary aerosols will need to be clarified, as the combined effect changes sign in 2020 compared to 2007.

In this report, we estimated marginal external costs with no real distinction between transport modes. Further research is needed to make separate estimations for the different transport categories: road, rail, inland navigation, sea shipping and air traffic.

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Annex 3 to the final report of the **LIMOBEL** project (Long run impacts of policy packages on mobility in Belgium), study financed by the Belgian FPS Science Policy.
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LIMOBEL Annex 3

Literature review for ISEEM and LIMOBEL

12 March 2008

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List of abbreviations

CBA	Cost-benefit analysis
CES	Constant elasticity of substitution
CGE	Computable general equilibrium
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CRIA	Constant relative inequality aversion
CRS	Constant returns to scale
D-S	Dixit-Stiglitz
DSGE	Dynamic stochastic general equilibrium
EU	European Union
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Greenhouse gases
HCFC	Hydrochlorofluorocarbon
KLE	Capital-labour-energy
LES	Linear expenditure system
LUCC	Land-use/cover change
MES	Minimum efficient scale
NEG	New economic geography
NH_3	Ammonia
PC	Perfect competition
PFC	Perfluorocarbon
PM_{10}	Particulate matter with a diameter smaller than 10μm
R&D	Research and development
SO_x	Sulphur dioxides
TFP	Total factor productivity
VAT	Value added tax
VOC	Volatile organic compounds

I. Introduction

The aim of this report is to give an overview of the relevant literature for long-term economic modelling. The review was conducted in the framework of the ISEEM and LIMOBEL projects, two projects financed by the Belgian Federal Science Policy office. Since the aims of the two projects were similar at this stage, it was decided to join forces for this task. The literature review is the result of a close collaboration between the research team involved in the two projects. However, since the aims of LIMOBEL and ISEEM are different, the conclusions drawn from the literature review for the economic modelling differ in the two projects. These conclusions are described in separate notes.

The next two paragraphs give a short description of the two projects. Next, we turn to the literature review, which covers both applied and theoretical models.

A. LIMOBEL: a short description

The aim of LIMOBEL is to develop a fully operational modelling tool to study the impact of transport policies on the economy and on emissions. The project will produce long-term projections (up to 2030) of passenger and freight transport demand in Belgium. A baseline scenario will be constructed which will be compared with alternative policy scenarios for more sustainable transport. In the alternative policy scenarios packages of instruments will be considered, including pricing instruments, regulation and infrastructure measures. Besides transport instruments the project may also consider more general instruments (such as labour taxes, transfers) in order to ensure budget neutrality. A cost-benefit analysis will be made of the policy packages.

The LIMOBEL modelling tool consists of three components: a model to determine long-term transport projections, a network model that assigns the transport flows to the network and an environmental model. The present paper provides an input in the first of these components. More specifically, the model for long-term transport projections incorporates a long-term economic model in which the interactions between transport and the economy are incorporated explicitly.

B. ISEEM: a short description

The ISEEM project develops and implements for Belgium an integrated spatio-economic-ecological modeling approach, which can be used to assist policy makers in their choice of long-term sustainability policies. The project aims to represents the state-of-the-art in different areas of economic, transportation, land-use and environmental modelling.

More specifically, the project builds a general equilibrium model of the New Economic Geography type (NEG). This refers to a class of economic models that looks not only into the equilibrium in the economy of a single country, but takes into account regional economic effects such as concentration and specialization of sectors, regional labour market effects, regional economic disparity, etc.

II. The Applied Models

A. The models under review

Before we plunge into a detailed description of the modelling practice, we first present an overview of the different models we have reviewed in this literature survey. The models we reviewed can be classified according to a few broad categories. Next to the more conventional CGE models[1], we distinguish a group of applied models making use of New Economic Geography theory which we shall refer to as the "NEG CGE models". Next to these two broad categories, we distinguish the land–use and transportation interaction models and models integrating economic systems with ecosystems. In a last category ('macro–economic models') we lump together two *sui generis* models, the macro–econometric model of NEMESIS and the neo–classical growth model of Mobilec. Table 1 gives an overview of the applied models considered here.

[1] Computable General Equilibrium (CGE) models are simulations that combine the abstract general equilibrium structure formalised by Arrow and Debreu with realistic economic data to solve numerically for the levels of supply, demand and price that support equilibrium across a specified set of markets. They are a standard tool of empirical analysis, and widely used to analyze the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets, or contain menus of different tax, subsidy, quota or transfer instruments.

Table 1: Overview of Applied Models

Model type	Models reviewed	Main source
Conventional CGE	GEM–E3	Capros et al. (1997) and
	GEM-E3 – regional version for Belgium	Saveyn and Van Regemorter (2007)
	EPPA	Paltsev et al. (2005)
	Greenmod II	Bayar (2006)
	Mayeres (1999)	Mayeres (1999)
	MMRF–Green	Adams et al. (2002)
	EDIP	Ivanova et al. (2007)
NEG CGE	CGEurope I and II	Bröcker et al. (2001, 2004)
	RAEM 2.0 and 3.0	Thissen (2004) and Ivanova (2007)
	REMI	REMI (2007)
Transport–land use interaction	RUBMRIO	Ruiz Juri and Kockelman (2003)
	RELU	Safirova et al. (2006)
Integrated economic–ecological models	GEEM–Alaska	Finoff and Tschirhart (2004)
Macro–economic	NEMESIS	Nemesis (1999)
	Mobilec	Van de Vooren (2002)

1. The conventional computable general equilibrium models

The **GEM–E3** model ('General Equilibrium Model for Energy–Environment–Economy interactions') aims at modelling the relationship between macro–economics, energy and the environment. Developed under the auspices of the European Commission, it focuses on the European level (as a whole or differentiated by country). In an environmental module, it considers policies with regard to energy related pollution. Some of the main applications are:

- The examination of the impact of creating a market of tradable pollution permits within the EU;
- The evaluation of macro–economic implications of the EU's targets for the Kyoto negotiations for greenhouse gas mitigation;
- The study of a possible "double dividend" for environment and employment.

Its multi–country and multi–sector design makes it possible to analyze distributional consequences of the aforementioned policies, within countries and among agents. The allocation of capital, trade and the impact on government finances and the current account can be analyzed. Its time horizon is 30 years. It comprises 18 sectors of production. The GEM–E3 model is extended to incorporate imperfect competition and increasing returns, making it particularly useful to analyze the above question with European integration at the background. A regional version of GEM–E3 has been applied for Belgium by Saveyn and Van Regemorter (2007), to evaluate the impact of different air pollutant abatement policies on the Belgian regions.

The **EPPA** model is the workhorse of the MIT Joint Program on the Science and Policy of Global Change. It is a recursive–dynamic multi–regional model of the world economy. It aims to develop long term (100 year) projections of economic growth and anthropogenic emissions of greenhouse gases and aerosols. EPPA is integrated as the 'human activity' module in a wider integrated global system model, but can also be used as a stand-alone model. Some of the policy questions that are addressed with the model include the economic implications of the diverse emissions mitigation policies. In this review, we made use of the 4th version of EPPA, as described in Paltsev et al. (2005).

The **Greenmod II** model is a multiregional model for Belgium similar to EPPA, aimed at being the first multi–regional, multi–sectoral CGE model of the Belgian economy that can be used to evaluate the regional effects of different environmental and energy policies. It aims to take into account the complex interdependencies between Belgian regions, and also includes a representation of different income categories to analyze interpersonal distributional issues.

The model of **Mayeres** (1999) seeks to shed light on improved transport pricing in the light of various externalities, given the need of policymakers to raise revenue through distortionary taxation and the need for an equitable distribution of the tax burden and feedback effects. Policy instruments include peak road pricing, higher fuel taxes, public transport subsidies, which are weighed against lump sum transfers and labour income taxes. In this respect, the study is closely related to the double dividend literature. To this end a static CGE model for Belgium is developed. There is no regional breakdown.

The **Monash Multi–Regional Forecasting (MMRF)–Green** model is a multi–regional, dynamic, computable general equilibrium model. It distinguishes up to eight Australian regions and, depending on the application, up to 144 commodities/industries. The model contains a module able to capture energy usage and greenhouse gas emissions by fuel, user and region. It fits in the tradition of Johansen/ORANI models, using a system of linearised equations. Policy questions that are answered through the model are the effects of regional infrastructure projects and the effects of different policies to reduce Australian emissions of CO_2 in line with Kyoto commitments.

Finally, **EDIP** is designed to evaluate income distribution and inequality effects of economic and environmental policies. Its relative strength comes from the detailed way in which different household types and transport sector are represented.

2. New economic geography computable general equilibrium models

A distinct class of CGE models is the so–called "NEG CGE models", explicitly incorporating elements from the New Economic Geography literature. The principal aim of the models considered is to analyze the (spatial) economic impact of new transport infrastructure. Economic impacts have to be understood as indirect effects (for example: migration, improved market access and access to varieties, possibly leading to agglomeration). Other policies with a possible regional impact (e.g. capital income taxation) may be analyzed as well. Models in this tradition are CGEurope, RAEM and REMI.

The **CGEurope** models have been designed mainly to analyze the static impacts on regional welfare of different EU transportation policies These projects comprise of new network links: high speed railways, conventional railways, roads (either in the EU–15 or EU–27), pricing scenarios such as the introduction of social marginal cost pricing and the development of a dedicated rail network scenario. The impact on some 1372 European regions (in the EU–27 and non–aligned European nations) is studied. The CGEurope models examine indirect effects on welfare through improved accessibility, but model only limited agglomeration effects. The CGEurope I model is able to provide simulations at the greatest level of regional detail but is limited in sectoral detail, whereas the CGEurope II model provides more sectoral detail (8 sectors), but uses a lower level of regional disaggregation (288 regions).

The different versions of the RAEM models are developed for the Netherlands. They distinguish 40 regions. The **RAEM 2.0** version allows for agglomeration effects through migration. It has, for example, been applied to examine the spatial effects, such as job reallocation, of a new railway link from the Dutch Randstad (Amsterdam) to the province of Groningen. **RAEM 3.0** extends its predecessor by incorporating dynamics, extending the government sector, introducing a foreign sector, making unemployment endogenous and introducing passenger trips in a more detailed way.

REMI Policy insight is a structural forecasting and policy analysis model. It integrates methods from several other model types to help its user understand the total macro–economic effects of policy decisions. It has the inter–industry detail available from input–output models. It allows for behavioural reactions to housing and consumer prices, wages and production costs, as in computable general equilibrium models. Dynamic responses and other parameters are estimated using econometric methods. It represents various agglomeration effects using new economic geography theory. The model incorporates some agglomeration effects not found in other models, such as the 'labour access' effect. The model has been used to evaluate the effects of various EU investments (transport and non–transport related) on the regional economies of Southern Italy and Andalucia (Spain). It has been recently applied for Belgium and used by DG REGIO for the analysis of the use of its cohesion funds.

3. Land use and transportation interaction models

A distinct kind of models tries to capture in more detail the interaction between transportation and land use. RUBMRIO and RELU are two examples of this kind.

RUBMRIO is a transportation economic model that simulates the flow of goods, labour, and vehicles across a multi zonal area (e.g. across the 254 counties in the state of Texas, as well as domestic export shipments to 49 U.S. States and foreign export shipments to 18 ports). RUBMRIO simulates trade flows across zones in a region, as motivated by foreign and export demands, and computes this trade across numerous economic sectors. Input–output relationships/tables are used to anticipate consumption needs of commodity producers, and multinomial logit models distribute commodity flows across origin zones and shipment modes. The model incorporates two factor markets, namely labour and floorspace. It has been used to predict the spatial redistribution of economic activities, population, rent and wages following the implementation of a large transport infrastructure project in Texas.

RELU is a spatially disaggregated CGE of a regional economy that is grounded in micro–economic theory and can be used for comprehensive welfare analysis. In order to shed light on the nature of interaction between land use, transportation and other forces in the regional economy, RELU is supposed to be integrated with a detailed transportation model. It has been applied to evaluate the land use effects of road pricing policies.

It should be noted that RELU and RUBMRIO are not situated in the New Economic Geography tradition. They do not exhibit the NEG's distinguishing features such as increasing returns and the preference for variety, and so do not capture the circular causality of NEG models.

4. Integrated economic–ecological models

Next to the classical CGE models, we consider an integrated **Economic–Ecosystem model, applied to Alaska**. The basic philosophy behind that model is the following: ecosystems and economies are jointly determined, and both systems are general equilibrium in nature. The particular model considered links the Alaskan economy to an 8 species marine ecosystem, including an endangered species (the Steller sea lion), through the fisheries and tourism sector. The impact of some fishing restrictions is then analyzed. In our review we will only discuss this model in the section on modelling the environmental impacts (Section II.H).

5. Macro–economic models

NEMESIS is a large macrosectoral econometric model of the European economy (with the US and Japan being included), aiming to give short and medium term forecasts, and to treat policy issues related to the environment and R&D. It builds upon the E3ME model, with more user friendly software, a new version of the energy / environment module and with the incorporation of recent economic theory developments on R&D and innovation spillovers.

Mobilec is a modified neoclassical growth model. It describes the relationship between the economy, mobility, infrastructure and other regional features in an interregional dynamic way. A main characteristic of the model is the representation of the two-way interaction between economy and mobility. In the traditional transport models transport is estimated as a derived demand of the economical development scenarios. The Mobilec model also determines the contribution of infrastructure to economic development, by including transport (productive mobility) in the production function. Outputs are time paths on macroeconomic aggregates, freight transport by modes within and between regions and passenger transport by modes, commuting, business and other purposes.

B. Firm behaviour

When reviewing the modelling of firm behaviour, one has to answer following questions:

- Which arguments enter the production function?
- What is the functional form of the production function?
- Does the production process exhibit economies of scale?
- How does competition take place, i.e. what is the market structure?
- Does the model incorporate any elements of new economic geography, and if so, which ones?

Table 2 summarises the discussion.

Table 2: The representation of producer behaviour

	No. of industries	Capital in production function?	Vintage capital?	Labour by skill group?	Functional form	Regional capital mobility?	Sectoral capital mobility?	Scale economies?	Market Form	'Love of variety' inputs?	Labour access effect?
GEM–E3	18	Y	N (Y in extension)	N (Y in extension)	CES	N (Y in extension)	Y/N (optional)	N (Y in extension)	PC (Cournot / Bertrand in extension)	N (Y in extension)	N
Greenmod II	62	Y	Y	N	Leontief/ CES	N	N (even for malleable part)	Y	Cournot and Monopolistic competition	N	N
EPPA	5	Y	Y	N	Leontief/ CES	N	Y (malleable part)	N	PC	N	N
Mayeres	12	Y	N	N	Leontief/ CES	n.a.	Y	N	PC	N	N
EDIP	59	Y	N	N	Leontief/ CES	N	N	Y	D–S	N	N
CGEurope I	6	K and L Lumped together	N	N	Cobb–Douglas	N	N	N / Y	PC / D–S	Y	N
CGEurope II	3		N	N	CES	N	N	Y	PC / D–S	Y	N
Raem 2.0	14	N	n.a.	N	Cobb–Douglas /CES	n.a.	n.a.	Y	D–S	Y	N

	No. of industries	Capital in production function?	Vintage capital?	Labour by skill group?	Functional form	Regional capital mobility?	Sectoral capital mobility?	Scale economies?	Market Form	'Love of variety' inputs?	Labour access effect?
Raem 3.0	14	Y	N	N	Cobb–Douglas /Leontief /CES	N	N	Y	D–S	Y	N
REMI	26 - 30	Y	N	Y	Cobb–Douglas /CES	N	N	Y	D–S	Y	Y
MMRF - Green	13	Y	N	Y	Leontief/ CES	Y	N	N	PC	N	N
RUBMRIO	21	N	N	Y	Cobb–Douglas implied	N	N	N	PC	N	N
RELU		Y	N.	Y	Cobb–Douglas /CES	Y	N	N	PC	N	N
GEEM Alaska	3	Y	N	N	CES	Y (between Alaska and RoW for 1 sector)	Y	N	PC	N	N
Mobilec	1	Y	n.a.	N	Cobb–Douglas	Y	n.a.	N	PC implied	N	N
NEMESIS	30	Y	(capital quasi fixed factor)	N	McFadden Cost function	N	N	Y	Monopolistic Competition	N	N

PC: Perfect competition; D–S: Dixit–Stiglitz monopolistic competition; n.a. : not applicable

1. The production function and production factors

It is obvious that the choice of which production factors to include, depends greatly on the purpose of the model. The most extensive production functions, with several nests reflecting the choice between several detailed inputs, are found in the environmental models. These models must of course capture the most complex substitution mechanisms between different kinds of polluting inputs. Usually models such as these will provide different production functions for different sectors.

The GEM–E3, Greenmod II and EPPA models are three models concerned with the economic effects of the abatement of greenhouse gases. The production functions in these models capture a wide range of inputs. Next to capital and labour, electricity, fuels and a wide range of intermediates are usually included. The level of detail ranges from 3 fuels (coal, oil, gas) in the GEM–E3 model to 9 in the Greenmod II model. The GEM–E3 model only allows for one nested production function for its 18 sectors.[2] The production function consists entirely of CES nests. The Greenmod II model distinguishes three groups of sectors ('conventional' energy producers, agriculture and 'other industry and services') and 2 sectors producing backstop energy (Coal gasification and carbon-free electricity generation). The EPPA model considers 5 groups of sector (Refined Oil, Primary energy, Electricity, Agriculture and 'Energy Intensive, Transportation and Other industries and services'. Different substitution elasticities for different sectors within the latter group are allowed for. Next to these 5 sectors, 4 backstop energy sectors are modelled (Shale oil, Wind and Solar, Coal gasification and Advanced Fossil electricity). A noteworthy feature of the EPPA electricity production sector is that it allows various substitution possibilities between different generating technologies. Conventional suppliers are supposed to be perfect substitutes with each other and most backstop technologies. Solar and wind energies are modelled as imperfect substitutes for all other sources, due to their erratic supply.

The use of vintage capital specifications is sometimes used in the environmental models. New capital installed at the beginning of each period is malleable, i.e. highly substitutable. At the end of a period, a part of this malleable capital becomes rigid, and frozen into the prevailing techniques of production. The remaining malleable portion can have its input proportions adjusted to new inputs prices or can be reallocated to other sectors. Each of the capital vintages is tracked through time as a separate capital stock. Production that uses a vintage of rigid capital is subject to a fixed coefficient transformation process in which the shares of capital, labour and energy are identical as in the first year of the vintage. None of the stocks of rigid capital are subject to improvements in energy efficiency. The vintage capital structure is thus one way of slowing down the effects of environmental policies or energy price movements.

[2] Though different parameters for different sectors can be calibrated, of course.

Mayeres (1999), which focuses heavily on transportation, uses nested CES functions considering 12 main sectors. These 12 sectors are divided into 4 groups using different production functions. Inputs include among others business transport and freight transport. A distinction is made between different transport modes, and between peak and off–peak transport (for road transport). The transport labour costs depend on the level of congestion.

The NEG models we reviewed in general use less sectoral detail and less elaborate production functions. Their focus lies less on describing the production process in detail to unravel the different substitution mechanisms between value–added factors and different kinds of energy, than on capturing spatial effects.

The RAEM 2.0 Model for example, just uses a two tier production function. The first tier uses a Cobb–Douglas function with labour and intermediate inputs. Note that capital is not included. Labour is the only value added factor, and is assumed to be mobile across sectors. This choice is certainly driven by the need to keep the model simple, since its focus is on agglomeration through the interaction between labour mobility and firm location decisions (as in the standard core -periphery model of New Economic Geography). In any NEG model the choice of which inputs to include, and of the degree of mobility of these inputs, is crucial to the nature of spatial effects. The RAEM 2.0 model thus rules out agglomeration through capital mobility. The second tier in the production function distributes the amount of intermediates demanded among the different suppliers according to a CES function. This way of modelling relates closely to the classic NEG 'love of variety' concept that will be described in the section on consumer behaviour. (section 1.3.) Due to the CES specification, the production function exhibits internal economies of variety. An increased diversity of inputs allows producers to use a more roundabout production process and lower unit costs at given input prices. In a spatial framework, this implies that producers will want to locate in a region with better access to the greatest variety of inputs, thus inducing an agglomeration effect. The strength of this effect depends on the elasticity of substitution. The lower this elasticity, the higher is the productivity gain from input diversification. The strength of this effect will depend on the industry. For example, electrical equipment industries, machinery and cars are dependent on specialised inputs which cannot easily be substituted, so input variety effects will be stronger for these industries. The substitution elasticity should thus be estimated / calibrated for each industry. In general, this is not done because of the lack of reliable sectoral time series data.

The production functions in the CGEurope I and II models seem to be modelled in a similar way. They consist of nested CES functions, the lower nest being a CES aggregate over different intermediate inputs. (In CGEurope I the first level of the production function is Cobb Douglas.) It should be noted that the production function consists of one value added factor, which is assumed to be immobile across regional borders. The model thus rules out a self reinforcing process of agglomeration due to factor mobility (usually dubbed 'circular or cumulative causation', according to Myrdal (1957)) that is so typical for many of the New Economic Geography models. In the absence of factor mobility, the spatial effects of infrastructure improvement on the different European regions from this model should thus be considered as short term effects. CGEurope I makes a distinction between a local goods and a tradable goods sector. CGEurope II does not make such a distinction.

We find many elements of the above in the REMI model. Its Cobb–Douglas production function consists of labour, capital, fuels and intermediates. A novel element in the REMI model is that different kinds of labour – according to occupational group – are allowed. Labour is mobile across borders. The model contains an equation measuring the productivity of intermediate inputs depending on the effective distance of the input supplier and a sector specific productivity advantage parameter, which is just the substitution elasticity between intermediates in the lower nest of the production function.

The REMI model introduces a novel spatial effect relating to the access to specialised labour. Labour productivity is made dependent on the access to specialised labour in a region. For each occupation, a labour productivity equation is calculated. Occupational productivity is dependent on the *number* of all potential workers and their commuting cost to that region. The number of potential workers is the main determinant of productivity, since it is assumed that even within occupational categories each single worker brings a set of unique skill to the firm. The greater the pool of workers, the higher is the chance that the best man for the job can be chosen. Again, the strength of this effect is determined by an elasticity parameter, by occupation.

The growth model of Mobilec uses the classic Cobb–Douglas production function, with the novelty that the arguments of the production function now include – next to capital and labour – productive mobility by mode between regions as inputs. This essentially captures the link from 'mobility to economy' as envisaged by the model.

In order to derive factor demand equations, NEMESIS describes the production process by a cost function, rather a production function. An average variable symmetric general McFadden cost function is used, which is improved to account for the presence of quasi–fixed factors of production such as R&D capital and physical capital. Variable inputs are labour, energy and materials. Using Shephard's Lemma, expressions for the factor intensities of variable inputs are derived. From an intertemporal cost minimisation program, dynamic quasi–fixed factor demands are derived. The cost function exhibits increasing returns. We note that the same dual form is used in GEM–E3.

In RUBMRIO (applied to Texas), producers face choices about input and labour origin over about 254 zones and a multitude of transportation modes. In RELU, producers decide on the location of labour hired, input and buildings. To capture the decision process of producers, discrete choice models are used. In RUBMRIO, trade disutility is measured by distance (as a proxy for transport costs) and input prices. The parameters are calibrated from a nested logit model on commodity flow data and Census data on county–to–county work flows.

2. Market Structure

The use of imperfect competition sectors is most prevalent, and indeed a necessity, in the NEG models. Imperfect competition is also found in GEM–E3 and Greenmod II. The land use and transportation models RELU and RUBMRIO assume perfect competition.

Firms in sectors facing imperfect competition are usually modelled as having economies of scale due to a fixed cost element in the cost function, usually consisting of fixed amount of labour, capital and/or fuel services. It is not always clear how models calibrate this crucial parameter. The GEM–E3 model estimates the fixed cost component using extraneous information at the industry level on the minimum efficient scale (MES) and cost gradients (the % increase in average cost when scale is reduced from MES to one third). If zero profits are assumed (in order to isolate marginal costs) fixed costs can be numerically calibrated. The MES information is also used to determine which sectors are designated as being imperfectly competitive. The modellers use the fact that under imperfectly competitive conditions the scale of production falls below the MES.

One encounters two main forms of imperfect competition in the models, oligopolistic competition and (Dixit–Stiglitz) monopolistic competition. The distinguishing feature between both kinds of competition lies in firm behaviour.

In the monopolistic competition case, the firm views itself as an atomistic part among a large number of firms, and does not engage in strategic behaviour. In this case the price–cost mark–up does not depend on the size of the market, and in combination with the usual Dixit–Stiglitz demand specification (explained in Section II.C.4), leads to a constant mark–up of prices over costs. Together with the assumption of multiplicative transport costs (made in all NEG models), this implies so–called mill pricing, leading to the same production price for goods sold in every region. This result explains the huge popularity of Dixit–Stiglitz monopolistic competition in economic geography models, since the assumptions provide for analytically tractable results and a controllable amount of equations when the number of regions gets fairly large. Another implication of this specification is that firm scale only depends on the cost parameters and the elasticity of demand, and is thus invariant to market size. Market size only influences the number of varieties. Note that not all models introducing monopolistic competition will use the Dixit–Stiglitz kind, which is a special case due to its CES demand specification.

The oligopolistic competition case assumes strategic interaction by producers, so that firms recognise their own market power. Price–cost margins will be higher, will depend on the number of firms and will thus react to the size of the market. (Note that the assumption of mill pricing will therefore not hold, so that in extremis one will have to calculate one price for each region. Most models limit the degree of regional price discrimination, though.) Increasing market size leads to more competition due to entry of firms, which will reduce price–cost margins and causes suppliers to operate at larger scale. In new economic geography terms, this is a pro–competitive effect through which regional market size lowers regional prices which complements the usual effect of increasing variety on the region's 'perfect' price index, as well as a cost of living effect which, in the case of agglomeration, reinforces demand linked circular causality (Fujita et al., 1999). Both GEM–E3–IM (the extension with imperfect competition) and Greenmod II (which are no NEG models) allow for such market form. The Greenmod II model imposes a zero profit condition, which allows one to compute the equilibrium number of firms thanks to the fixed cost component per sector. GEM–E3–IM allows for two mechanisms in which the equilibrium number of firms is computed. The first uses the zero profit condition to ensure instantaneous adjustment of firms in each period, the second takes the number of firms in one period to be fixed, and lets the number of firms adjust in the next period according to an ad hoc equation.

The GEM–E3–IM model lets each producer calculate 3 prices, one for the domestic market, one for the EU market, and one for the rest of the world. The way the mark–ups react to market conditions, depends on the type of competitive regime chosen, either through Nash–Bertrand or Nash–Cournot. In setting prices, the firm will have to conjecture on changes in the competitive environment, either from a change in the number of firms or the opening of markets, and the change in the shares of domestic and imported goods in final demand. In setting prices for the rest of Europe, firms are assumed to take into account a weighted average of perceived demand elasticities. Since computational resources for such a calculation may be unrealistically demanding, bounded rationality of the firm is assumed. We note that, contrary to GEM–E3–IM, the Greenmod II model does not allow for any price discrimination between the home region and the other Belgian regions. The same assumption is made for the regional GEM–E3 model of Saveyn and Van Regemorter (2007).

It may be worth noting that CGEurope II uses a modified version of the standard Dixit–Stiglitz monopolistic competition. They allow for a 'degree of monopolistic competition', so that every sector is situated between perfect competition and pure monopolistic competition. In this case some degree of market crowding may be allowed for in partially monopolistically competitive industries. With full market crowding, an increase in market supply then has its full impact on supply prices. Agriculture is seen as perfectly competitive, services as close to Dixit–Stiglitz, industry as lying in between.

From the review, it should be clear that the distinction between Dixit–Stiglitz monopolistic competition and Cournot oligopolistic competition is an important one. The former is routinely used by the NEG models; the latter seems prevalent in the environmentally related models.

Dixit–Stiglitz competition has proven to be important in the theoretical NEG literature due to its tractability. There is no reason to assume, however, that other market forms cannot generate the same economic geography results, as long as increasing returns to scale and the love of variety in consumer preferences are included. Increasing returns to scale are necessary to derive an endogenous number of firms (and thus of varieties) which can be done both in the Dixit–Stiglitz framework, as well as in the Cournot framework. The CES consumer preferences over a number of varieties can also be retained in both cases, as is done in the GEM–E3 imperfect competition extensions. But even CES preferences are not an absolute necessity. It is well know that quasi linear quadratic preferences can yield the love of variety too, as is shown in Baldwin et al. (2003). A number of theorists have worked on developing NEG models without the restrictive features of Dixit–Stiglitz monopolistic competition (See e.g. Ottaviano et al., 2002).

As for the importance of market structure for environmental modelling, there is a large literature on how optimal environmental policy should be set in the face of different market structures. One example can be found in Requate (2005). He describes how optimal Pigouvian taxation differs when applied to an industry characterised by Dixit–Stiglitz monopolistic competition or Cournot competition with free entry.

3. Land and housing markets

In NEG models, the housing/land market may play a crucial role in determining the nature of agglomeration in the model. In many of the first theoretical models agglomeration was said to be irreversible once transport costs are lowered beneath a certain threshold. Further economic integration would only sustain the agglomeration pattern, since in those first models both the dispersion and agglomeration forces decline in strength with falling trade costs, but the dispersion force does so at a higher rate than the agglomeration force. This results in the familiar pattern of agglomeration at 'low' costs, and dispersion at 'high' costs. Including a dispersion force which does not depend on trade costs but only on regional density, would alter this pattern and create an opportunity for re–dispersion if trade costs fall any further (because agglomeration forces diminish in strength relative to the stable dispersion force) and would generate more realistic degrees of clustering, apart from the '100% or nothing' that is found in the theoretical models. The housing market is a first candidate to play this role (see also Helpman, 1998).

Most models do not include a separate housing market. In the RAEM 2.0 model, housing does enter the overall consumer utility function and plays a crucial role as an additional dispersion force. The housing stock is kept at an exogenous fixed level, even though the scenario where housing becomes important is described as the 'long run' case. Additional migration to a region will lower the amount of housing per capita, which in turn lowers utility from living in a region.

The RELU model includes equations describing a floor space market with consumer and landlord behaviour. The amount of floor space is determined by the amount of buildings, which is in turn determined by the behaviour of real estate developers. Landlords decide to rent out a unit of floor space, depending on costs common to all landlords, and a random i.i.d Gumbel cost component. From this the probability that a landlord rents out floor space is derived, which determines the overall supply. Consumers' demand of floor space, by type, is determined by a Cobb–Douglas utility function. The total stock of buildings is determined by the decision of developers to construct or demolish. The value of buildings will depend, among others on rents, which are weighed against maintenance costs.

RUBMRIO also models the housing market, but keeps floor space supply (in the short run as well as in the long run) fixed, so that all changes in rents are demand driven.

C. Household behaviour

Models aiming at capturing the relationship between policy, the economy and the environment, need to capture the relevant choices made by economic agents, of which households are among the most important. Responses in demand, driven by policy–induced price changes are of the highest importance to final outcomes. In this paragraph, we will review how consumer demand has been modelled in the various models under consideration. Table 3 gives a summary of the discussion.

Table 3: The representation of household behaviour

	No. of commodities	Labour Supply (Leisure in utility function)	Time in utility function ?	Externalities in utility function?	Functional Form	Linkage Durable / Non-durable ?	'Love of variety'	Armington preferences	Different household groups? Per country / region?
GEM–E3	11 nondurable 2 nondurable	Y	N	Y (separable)	LES (lower CES nests in extension)	Y	N (Y in extension)	Y	N
GreenMod II	67 other 2 energy	Y	N	N	LES	N	N	Y	Y
EPPA	12	N (Y in extension)	N	N	CES	N	N	Y	N
Mayeres (1999)	36 transport 4 energy 1 other	Y	Y	Y (separable + non–separable)	LES/CES	Y	N	Y	Y
EDIP	59	Y	Y	Y	LES/CES	N	N	Y	Y
CGEurope I	7	N	Y	N	CES	N	Y	N	N
CGEurope II	7	N	Y	N	CES	N	Y	Y	N
RAEM 2.0	14	N	N	N	LES/CES	N	Y	N	N
RAEM 3.0	14	N	N	Y	LES/CES	Y	Y	Y	N
REMI	13	n.a.	n.a.	n.a.	n.a.	N	Y	Y	Y
MMRF–Green	13	N	N	N	LES/CES	N	N	Y	N
RUBMRIO		N	N	N	n.a.	N	N	N	N
RELU		Y	N	N	Cobb-Douglas/CES	N	N	Y	Y

	No. of commodities	Labour Supply (Leisure in utility function)	Time in utility function ?	Externalities in utility function?	Functional Form	Linkage Durable / Non-durable ?	'Love of variety'	Armington preferences	Different household groups? Per country / region?
Mobilec	Aggregate output + consumptive travel	n.a.	n.a.	n.a.	Fixed proportion of output	n.a.	n.a.	n.a.	n.a.
NEMESIS	27	n.a.	n.a.	n.a.	Econometric demand system (CBS version)	N	N	n.a.	N

n.a.: not applicable

1. The components of the utility function

First, a decision has to be made on the arguments that enter the household utility function. The most general functional form of utility (in a static framework[3]) is the following.

$$U = U(C, L, T, G, E)$$

Utility consists of utility out of consuming commodities (C) (transport and non -transport related), leisure (L), time spent on various activities, including transport (T), public goods (G) and disutility out of negative environmental externalities (E). All the models we consider use a variant of this general utility function, with arguments chosen in function of the purpose of the model. Variations on the above function can choose to include arguments for time, public goods and externalities in a separable way or not, which matters greatly for the amount of substitution between different arguments and related feedback mechanisms (see also Section III.E).

In most models leisure enters the utility function, which implies that labour supply is determined endogenously. Modelling labour supply may be quite important when analyzing the labour supply effects of different forms of environmental and transportation reform packages. The distortionary effects of labour taxes are, for example, frequently used by the so–called double dividend literature, which investigates whether the introduction of a revenue neutral externality tax leads to an increase in welfare, even when not taking into account the impact on the externality. An example of such a study can be found in Mayeres (1999). The more NEG oriented models like RAEM 2.0 and CGEurope do not include leisure in the utility function. RELU models the choice to be unemployed as a discrete choice problem. In this case, there is no income effect which rules out a backward bending labour supply curve.

Few models explicitly include the time spent on transportation in the utility function. The CGEurope models take a negatively additive separable function of travel time in the utility function, since its main goal is to analyze the changes in of welfare due to improvements of transport infrastructure, i.e. lower travel time between European regions. The model of Mayeres also takes into account travel time (for each transport commodity considered), but in a different way. Here time enters the utility function in a non–separable way. This is done to capture the feedback effect of congestion abatement. In this case, non–separability would lead the consumer to consume more transport services if the level of congestion goes down, thus dampening the effect of policies to reduce congestion. The (dis)utility from travel time is made endogenous in the model. The RAEM 3.0 model accounts for the changes in time costs of passenger trips. An

[3] The savings decisions of households are discussed in Section II.J.1.

increase in the time costs of passenger trips reduces the available regional labour endowment and, hence the amount of labour, which can be used for production.

In a simple growth model such as Mobilec the focus is on production, so consumption plays only a minor role. Aggregate consumption is exogenously determined by the regional product by a constant saving rate, just like consumptive mobility, which is a fraction of regional product and a function of prices. Travel time shows up in real prices, and is the result of aggregate capacity utilisation.

2. The budget constraint

Most models, with the exception of Mobilec, define an explicit consumer utility maximisation problem under a budget constraint. The extensiveness of this budget constraint varies across the different applications. In some instances, additional constraints, next to the classic budget constraint, are specified. Mayeres (1999), for example, makes use of time allocation constraints by transport activity, which specifies a minimum time requirement by activity. If these constraints are binding, the value of time spent in that activity is positive, so transport time used on transport is not considered to be part of leisure.

3. Durable non–durable linkage

Some models, such as the GEM–E3 model and the CGE model of Mayeres use a more sophisticated way of modelling the ownership and use of durables. They make use of the general demand system described by Conrad and Schröder (1991), where non–durable consumption is being divided in a part that is implied by the ownership of durable goods, and a part that is not. The latter part is called substitutable; the former part can be called 'committed'. Total utility is defined over the stock of durables, and the substitutable part of the non–durable goods. The cost of durables in the budget constraint does not only include the cost of purchase of the durable (including taxes), but also the operating cost in terms of committed non–durable goods. (This has been described by Conrad en Schröder as follows: if someone buys a durable only taking into account its own price and not the additional expenditure on non–durables associated with the use of the durable, he will violate his budget constraint later on). The result of such a specification is that a more detailed analysis of the effects of environmental policies can be performed. For example, a reduction in the committed expenditure of fuel in a car (for example due to increased economies in fuel consumption) may result in a higher demand for cars, and thus higher fuel consumption. Raising the fuel costs through taxes will not only result in less 'substitutable' fuel consumption, but also in a lower car stock.

In Conrad en Schröder's model the level of committed expenditure of non–durables is being modelled as 'technically determined' (i.e. exogenous). A different interpretation of the committed expenditure comes from Koopman (1995). The model assumes people only buy a car when they know they will drive a certain minimum amount of mileage with it. This is called committed mileage. All miles driven above this minimum mileage are termed supplementary mileage. The cost of the former includes besides the vehicle also the operational costs, while the costs of the latter include only the operational costs. The consumer chooses the level of committed and supplementary mileage. Deciding on committed mileage is equivalent to deciding upon the size of the car fleet.

The NEMESIS econometric demand model distinguishes non durables, durables and related non durable consumption. The model does not capture the durable / non–durable linkage, however.

4. The functional form of the utility function

After the decision on what to include in the utility function, one has to decide on the functional form. The most common specifications found in the literature are the CES and LES specification, usually combined in some sort of nesting structure. Sometimes the CES function appears in its Leontief version or the Cobb–Douglas version. Since the CES function is homogenous of degree one, it will produce unit income elasticities. This means a doubling of expenditure (or income) will leave the relative expenditures between categories unchanged. Of course this is highly unrealistic. The EPPA modelling team, which uses the CES specification throughout, acknowledges this feature may be a problem in their 100 year prediction horizon. Over 100 year (which – at a growth rate of 2% - implies an increase in income by factor 7.25) aggregate expenditure shares are bound to change, thus changing the composition of industrial production and ultimately the environmental impact of the economy. The EPPA model uses CES functions because they simplify the solution of the model. The problem of fixed shares is undercut by making elasticity and share parameters an explicit function of income. Most models, however, use the LES specification to attribute total expenditure to different goods. Of course, when saving is directly included in the utility function, using CES type functions will lead to a constant saving rate.

NEG Models, such as the RAEM 2.0 and the CGEurope models, usually rely heavily on Dixit–Stiglitz type monopolistic competition. The consumer in this market form is assumed to have CES type preferences defined over different varieties of the same good. The most important feature of this type of preferences is the so-called love of variety, which can be understood in different ways. One way of understanding it, is that a consumer will gain in welfare when the number of varieties at his disposal grows. Or, put in different terms, the price index associated with this preference structure will be lower, the more varieties there are. This 'love of variety' is an indispensable tool in analyzing the spatial distribution of consumers' utility, since it implies that consumers living in a region with access to a lot of varieties will need less expenditure to reach the same level of utility. The crucial parameter governing the strength of the love of variety is the elasticity of substitution of the CES function, with a higher substitutability reducing the strength of the preference for more varieties.

Another implication of CES preferences is that people would gain more utility from spreading a given amount of expenditure maximally on a given number of varieties. This observation leads to the so–called Armington assumption of preferences over product varieties from different countries. In practice this entails a lower CES nest allocating expenditure of a good over different import regions. The consumer will then want to spread his expenditure of goods over the different regions, leading to cross-hauling in international trade. Of course, models that use the Dixit–Stiglitz market structure implicitly use the Armington assumption. Virtually every model that incorporates a foreign sector and does not use Dixit–Stiglitz competition will explicitly introduce the Armington assumption.

In CGEurope II and RAEM 3.0 the decision tree involves an upper CES nest choosing from different supplying regions and a lower CES nest choosing from varieties within each region. The model thus incorporates two different substitution elasticities. The same combination of Armington preferences and preferences over regional varieties is found in GEM–E3. RAEM 2.0 and CGEurope I subsume both specifications.

The NEMESIS model makes use of an econometric demand system, relating log quantities to log consumption and log prices. Some restrictions on estimated parameters are imposed, ensuring consistency with rational consumer behaviour. The CBS version of the standard econometric demand system is used in the final estimation. It is assumed that demand will adjust slowly to its new equilibrium as a response to shocks, so an error correction mechanism is also estimated using the Engel–Granger two–step estimation procedure.

5. Household types

Most models consider one representative consumer. Therefore, they do not allow for an analysis of distributional issues. Exceptions to this are REMI, Mayeres (1999), Greenmod II, EDIP and RELU. The REMI model makes a distinction according to income group and age class. However, the behaviour of these consumer groups is not modelled explicitly. It is derived from an aggregate consumption function using correction factors for age and income levels. In Mayeres (1999), Greenmod II, EDIP and RELU different consumer groups are considered. Each of these groups is assumed to maximize its utility. Mayeres (1999) and Greenmod II use income to define the different groups. In EDIP consumers are differentiated according to income, education level and type of profession. RELU makes a distinction between 4 skill levels.

6. Some calibration issues

Given the crucial importance of the substitution elasticity in the 'love of variety' and Armington specifications, we will pay some more attention to the way this parameter is estimated in various models. In the imperfect competition part of the GEM–E3 model, the elasticity of substitution is calibrated given the formula:

$$N = Y / (\sigma * FIX)$$

N is the number of firms, calculated by the inverse of the sectoral Hirschman–Herfindahl Index and FIX is the estimated fixed cost of firms, calculated using minimum efficient scale and cost gradient estimates according to the method of Pratten (1988). Y is sectoral production. The elasticity of substitution σ follows from this formula given estimated values.

The CGEurope models use an estimation procedure based on the fact that the Armington substitution elasticity shows up in the distance function of the gravity equation of interregional trade. From this function, one can obtain the parameter estimate of a regression of the value of interregional trade and generalised distance between regions. Using this parameter and an independent estimate of the transport cost intensity (namely the average ratio of transport costs over the value of trade) the substitution elasticity can be inferred. Ideally, one would need interregional trade flow data for this exercise, but due to a lack of data availability the CGEurope team had to make use of international trade flow data.

D. The labour market

In our review of the way the labour market is represented in the different models, we paid particular attention to the following issues. Is the labour market modelled as the classical interplay between supply and demand with adjustment of the wage rate as the equilibrating factor? In such a setting, unemployment is taken to be voluntary. In this context we also find a number of models assuming a perfectly inelastic labour supply. Or is there some kind of labour market imperfection due to union wage bargaining? For dynamic models, the issue may arise whether some kind of nominal inertia will be used. MMRF–Green allows for a specification that holds wages sticky in the short run (employment effects of shocks disappear after 10 years). Likewise, the NEMESIS model uses an error correction mechanism to describe the adjustment of wages to their new equilibrium. Some models also pay particular attention to the search and matching process, for various reasons. For the models with a spatial touch, it is also interesting to check whether wage differentials between regions and migration or commuting are allowed. Table 4 summarises the discussion.

Table 4: The representation of the labour market

	Perfectly inelastic labour supply?	Wage bargaining?	Nominal inertia? (For dynamic models)	Search and match model?	Commuting between geographical entities?	Migration?	Uniform wage across geographical entities? ('regional' vs. 'national' market)	Skill/occupation groups?
GEM–E3	N	N (Y in extension)	N	N (Y in extension)	N	N	N	N (Y in extension)
GEM–E3 (Belgium)	N	N	N	N	Y (From the national labour market equilibrium condition)	N	N (only due to commuting costs)	N
Greenmod II	N	Y	N	Y	Y (exogenous)	N	N	N
EPPA	Y	N	N	N	N	N	N	N
Mayeres (1999)	N	N	n.a.	N	n.a.	n.a.	n.a.	N
EDIP	N	N					N	N
CGEurope (I,II)	Y	N	N	N	N	N	N	N
Raem 2.0	Y	N	n.a.	Y	Y (From the matching function)	Y	N	N
Raem 3.0	N	N	N	Y	Y (discrete choice)	Y	N	N

	Perfectly inelastic labour supply?	Wage bargaining?	Nominal inertia? (For dynamic models)	Search and match model?	Commuting between geographical entities?	Migration?	Uniform wage across geographical entities? ('regional' vs. 'national' market)	Skill/occupation groups?
REMI	N	N	N	N	Y	Y	N	Y
MMRF-Green	Optional	N	Y	N	N	N	N (exogenous or endogenous)	Y
RUBMRIO	Y*	N	N	N	Y (discrete choice)	Y (discrete choice)	N	Y
RELU	N	N	N	N	Y (discrete choice)	Y (discrete choice)	N (due to commuting costs)	Y
Mobilec	Y	N (wage exogenous)	N	N	N	N	N	N
NEMESIS	N	Y	Y	N	N	N	N	N

n.a.: not applicable

* Total labour force is a constant fraction of population, although labour will divide itself across regions according to wage differences.

GEM–E3 (in its core model), EPPA, EDIP and Mayeres (1999) model labour supply as the result of a decision of the households on the amount of leisure to consume. Unemployment is thus taken to be entirely voluntary. As has been said before, the decision to include the labour supply decision may be driven by the need to capture the distortionary effect of labour income taxation in order to be able to address the double dividend issue in these environmentally oriented models. The GEM–E3 model assumes a high elasticity of labour supply to capture the fact that in many European countries a fair amount of additional labour force is available to enter the labour market. Equilibrium in the labour market is given by the wage rate that equates supply and demand. Some New Economic Geography inspired models also make use of this Walrasian modelling of the labour market, but on top of this assume a fixed labour supply. The CGEurope models for example assume an immobile, fixed labour in every region, which is quite compatible with their short term horizon. The RAEM 2.0 model also assumes an exogenous labour supply, and models unemployment as the equilibrium result of a search and matching process. The REMI model is the only NEG model with an elastic labour supply curve. Labour force participation is made dependent on the wage and employment opportunities, the strength of which is allowed to vary across the different socio–economic groups considered.

The land use model RELU models the decision to work as a discrete choice, where the explaining variables are the wage and the outside option. Since leisure does not enter the utility function there are no income effects and so there is no backward bending labour supply curve. The elasticity of labour supply is determined by the relative weight of the idiosyncratic component and the wage related portion of the indirect utility function that derives from the discrete choice problem. RUBMRIO takes total labour supply as a fixed proportion of the population, and only concerns itself with the spatial distribution of labour supply, either through commuting or migration.

Only in some models, namely Greenmod II, NEMESIS and an extension of GEM–E3, is the assumption of competitive markets dropped and is the competitive labour supply curve replaced by a wage bargaining curve (determined according to Nickell's right–to–manage model.) NEMESIS uses an econometrically estimated wage equation, by industry and region, where wages depend on inside factors such as productivity and outside factors such as unemployment. Wages in GreenMod II are determined at the regional level, and by sector. From the GEM–E3 reference manual, it is not clear whether such sectoral disaggregation is made. Most NEG models assume a competitive labour market and ignore wage bargaining. In RAEM 3.0 however, a wage curve (relating unemployment negatively to the level of wages) is included in the labour market model. As is well known, the wage curve, which is an empirical phenomenon, can be interpreted both as an inverse labour supply curve, thus arising from the functioning of a competitive labour market, or as the result of union bargaining.

Some models find it useful to use elements from the search and matching model of the labour market (RAEM 2.0 and 3.0 and Greenmod II, albeit for different reasons). The usual specification is the model according to Pissarides (2000). This model views the co-existence of vacancies and unemployment as equilibria, rather than disequilibrium phenomena. Workers and firms engage in costly search to find each other. Firms spend resources posting vacancies and screening employees while workers spend time searching and applying. Workers and firms are assumed to be randomly matched. The model is formalised by a matching function (usually of the Cobb–Douglas type) relating the matches on the labour market to the number of vacancies and unemployed. From this and from information on the flow into unemployment a Beveridge curve can be derived, relating vacancies to unemployment.

The Pissarides search and match model is used in Greenmod II to calculate the probability that someone who becomes unemployed finds a job again. This probability shows up in the outside option of the employees, which is in turn a parameter of the utility function of the union in the bargaining problem. RAEM 2.0 uses the Pissarides model for a different reason. It is used as a gravity equation to describe commuter behaviour across regions, which is assumed to be the result of the unemployed searching for new jobs across all regions. Note that this specification thus rules out the possibility of 'on the job' search. The number of matches produced by the process determines a commuting matrix across regions. It should be noted that the matching function in RAEM 2.0 includes a term capturing the sensitivity of the labour market to the cost of travelling between regions. Estimating this sub–model entails the estimation of the Pissarides regional Beveridge curve, by minimising the relative quadratic distance between the estimated and the actual commuting matrix.

In RAEM 3.0, a different commuting generating function is used. The arguments in the pair wise gravity equation are no longer unemployment and vacancies (as in RAEM 2.0), but labour supply in a region *minus* unemployment and labour demand in the other region. The equation is scaled by an exponential function comprising the time and monetary costs of commuting, as was done in RAEM 2.0.

Commuting shows up in Greenmod II too, but is taken to be an exogenous share of total labour supply in each region.

Next to commuting, migration is another important aspect of spatial models, especially the ones which are situated in the NEG tradition. Indeed, the seminal core–periphery model of Krugman (1991) uses (labour) migration as one of the driving forces behind its most celebrated result. Most (non-NEG) models with a regional dimension do not model any migration between countries, which may be defensible given the geographic scope of the models (world regions in the EPPA model) or plainly the reality of limited international migration between EU countries (e.g., GEM–E3). As has been said before, CGEurope is the only NEG model not allowing for migration, most likely due to its European wide scope. A salient feature of the Belgian regional models, regional GEM–E3 and Greenmod II, is the absence of interregional migration, reflecting the limited migration from unemployment ridden Wallonia and Brussels to Flanders.

The REMI, RAEM 2.0 and 3.0 models do address interregional migration. The REMI model has been developed in the U.S., where interstate migration is prevalent, and applied to Italy and Spain, nations with fairly homogenous populations. The scope of the RAEM models is the Netherlands, which is also a very homogenous country.

In the RAEM 2.0 model, migration is allowed in the 'long run' version. In the short run version, with exogenous unemployment rates and commuting, utility differences between regions are allowed. The long run condition is that (relative) utility should be equalised across regions, so that the (exogenous) national population is being distributed across regions to satisfy this condition. Utility consists not only of the utility of consumption (heavily dependent on the regional access to varieties, see supra), but also on the utility of living in a region. This latter component depends solely on the stock of regional housing per person. Housing is assumed to be a normal good. The stock of housing is taken to be exogenous. There is thus no explicit housing market sub–model included. No other regional amenities – e.g. environmental congestion – are considered. The only additional dispersion effect is due to diminishing housing capacity per person.

In RAEM 3.0 migration is modelled by a two stage discrete choice decision process. In a first stage the decision to migrate is dependent on the difference between average utility across regions and regional utility. In a second stage, the total of migrating households is distributed among the regions according to region specific utility. Housing does not show up in household utility in the preliminary version of RAEM 3.0. Other models using discrete choice in migration (and commuting) behaviour are RELU and RUBMRIO.

The REMI model tackles the migration issue in a more detailed way. Migration for economic reasons and migration for non-economic reasons (e.g., military migration and retiree migration) are considered. We will focus on their treatment of economic migration. The driving forces behind the migration equation are wages and employment opportunities and the access to variety. People will also value some places more than other (e.g. sunny Florida). These non–economic amenities are captured by compensating differentials measured by looking at migration patterns over the last 20 years. (e.g. people would like to live in Florida even for 85% of the national average wage rate). The REMI model does not seem to take any congestion effects into account. Housing prices are a consequence of migration decision but not a cause for it, since they do not show up in the migration equation. There are no environmental congestion effects. For a theoretical model including spatially distributed environmental quality in a NEG model, see Friedl et al. (2006)

A last question for regional models, the answer to which may have quite profound implications, is whether wages are formed (or set) at a regional level or at a supra–regional ('national') level. Most models using competitive labour markets and no migration assume wages to be determined by market forces at the regional level. We mention one exception here: the GEM–E3 application for Belgium by Saveyn and Van Regemorter (2007). They apply GEM–E3 to the three Belgian regions, and thus find the labour immobility assumption of the GEM–E3 model to be insufficient in a Belgian context. Moreover, the inclusion of commuting behaviour in an environmental model of a federal state is important for the overall impact of a regionally diverse implementation of environmental policy instruments (see Saveyn and Van Regmorter, 2007). They therefore consider a national labour market, with the Walrasian condition that the sum of labour demand across regions has to equal the sum of labour supply, from which commuter flows follow. Regional wages are allowed to vary only due to commuting costs.

Nothing in the RAEM and REMI models would cause wages to equalise across regions. The models which assume imperfect competitive conditions on the labour market assume wage setting at the regional level too. However, this approach may not be a good representation of reality. In the Netherlands for example, the country which the RAEM 2.0 model is assumed to represent, wages are bargained at the sectoral level (i.e. nationally) with a strong influence of national macro–economic coordination. The same is true in Belgium (although the influence of national coordination is not that strong, sectoral bargaining is prevalent).

We note that an early predecessor of the RAEM 2.0 and RAEM 3.0 models (RAEM 1.0) recognised the facts of Dutch wage setting, thus only allowing for one wage rate in all regions. This is said to limit the incentives for regional labour mobility. It is not clear how this uniform wage is to come about. Note also that unions do not negotiate the real wage rate, or certainly not the wage divided by a perfect CES price index, which is bound to differ across regions. So there will still be source for migration.

The MMRF–Green model lets the user choose whether to keep labour supply fixed of flexible. More precisely, the modeller can choose whether to keep one of these three variables: regional labour supply, the regional unemployment rate or the regional wage differential (defined as the difference between the regional wage and the average national wage).

E. International trade

In most models, trade between the regions of the model economy is implied by the equations of the model itself. Usually demand will be distributed over the regions according to Armington preferences *(see above)*. When trade between the model economy and the rest of the world is included, additional foreign demand and supply equations must be specified. This section will deal with the modelling of trade with a 'rest of the world' entity, rather then 'interregional' trade between sub-entities of the model economy. Only RAEM 2.0 and RELU are closed economies. The discussion is summarised in Table 5.

Table 5: The representation of the 'rest of the world'

	Foreign sector?	Flexible current account?	Exogenous RoW?
GEM–E3	Y	Y / N	Y (N in extension)
Greenmod II	Y	N	Y
EPPA	n.a. (model captures whole world)	n.a.	n.a.
EDIP	Y	N	Y
Mayeres	Y	N	Y
CGEurope I	Y	n.a.	n.a.
CGEurope II	Y	n.a.	n.a.
RAEM 2.0	N	n.a.	n.a.
RAEM 3.0	Y	N	Y
REMI	Y	N	Y
MMRF-Green	Y	N	N
RUBMRIO	Y		Y
RELU	N	n.a	n.a.
Mobilec	N	n.a.	n.a.
NEMESIS	Y	Y	Y

n.a.: not applicable

In many models the behaviour of the rest of the world is very important to the final outcome of the model. To give an example from the environmentally oriented models: the enactment of climate policy in one country may induce a shift in demand from the expensive domestic goods to the more competitive foreign sector, thus dampening the overall positive effect on the environment, and worsening the position of the home country. The strength of this effect will typically depend on the elasticity of foreign export supply, and the substitutability of domestic goods for imports. In RUBMRIO, a spatial model, the demands from the foreign sector have an important influence on the distribution of economic activity in the economy, which does not change a lot precisely since foreign demand is assumed to remain fixed throughout the simulation.

It may be worth mentioning that next to the representation of export and import interaction, Mayeres (1999) also models the use of transit transport by the Rest of the World in the economy. This form of transport demand will depend on the relative price of transport abroad and at home. The price abroad is assumed to be fixed; the price at home will depend, among others, on externality taxation and the level of congestion.

To model the foreign sector one must consider in turn foreign demand, foreign supply, domestic import demand and domestic export supply.

In this respect, the assumption of a small open economy is very important, since it assumes the economy in question to be a price taker on the world market. This could be understood as the domestic sector facing perfectly elastic import supply and export demand from the rest of the world. Most models however assume some kind of imperfect substitutability between domestic goods and foreign goods

In the case of foreign demand for domestic goods models frequently make the *share* of the home country in RoW export demand dependent on the relative price at home and abroad, where the price abroad is taken to be exogenous, and on the total (exogenous) *volume* of demand for exports. These assumptions on the exogeneity of RoW prices respect the small open economy assumption. The foreign demand function contains an elasticity parameter. This specification is found in Mayeres (1999) and GEM–E3. Foreign export demand can also be made dependent on foreign income. The GEM–E3 model for example contains an extension where the increase of imports from RoW triggers a feedback effect, increasing RoW income and thus in turn raising exports, which is more in line with the modelling of the EU as a large economy. The MMRF–GREEN model uses finitely elastic foreign demand curves, with the novelty that these demand curves are distinct for each Australian region. In RUBMRIO, final demands from 'the rest of the world' outside Texas are exogenous just as final demand from inside Texas.

Regarding the foreign supply of imports many models take RoW prices as completely exogenous, thus assuming an infinitely elastic supply curve. This assumption is relaxed in an extension of the GEM–E3 model, where foreign supply is also taken to be finitely elastic. This would resemble reality more closely, given the size of the EU economy.

Domestic import demand usually also depends on relative prices and income. The strength of the effects depends on the Armington elasticity, which in virtually all models governs demand for foreign goods.

As regards domestic export supply, in some models domestic producers must explicitly decide on the allocation of production to the domestic market and foreign markets. This is modelled by including a constant elasticity of transformation production function over the domestic regions and foreign regions. In this way, the supply of exports to RoW by domestic producers will also depend on the elasticity of transformation, as well as on relative prices, so that domestic export supply will react more slowly to changes in the latter. This kind of modelling is found in Greenmod II and RAEM 3.0. Greenmod II only allows for this specification in the perfectly competitive sectors, however.

One further issue concerns the closure of international trade via the current account. Usually the current account is assumed either to balance, or to exhibit some predefined exogenous deficit/surplus (possibly over time). The exchange rate is then allowed to vary to satisfy the current account condition. The GEM–E3 model however allows for a flexible current account, the exchange rate being fixed.

F. Government, policy and welfare

1. The government sector

As far as the representation of the government sector is concerned, several choices must be made. How many government instruments should be represented? How many layers of government (and their interactions) must be included? How to treat the deficit?. It should also be noted that none of the reviewed models represents the government as an independent actor with its own utility function (e.g. revenue or welfare) to be maximised. This rules out the modelling of any strategic interaction between either different geographical entities or different layers of government. Government behaviour is thus completely exogenous. The closest to independent government maximising behaviour is the inclusion in GreenMod, Mayeres (1999) or RAEM 3.0 of a Cobb–Douglas utility function dividing exogenous government consumption over different expenditure categories. Table 6 summarises the discussion.

Table 6: The representation of the government

	Receipts	Spending	Multi–Layered?	Deficit possible?	'Manna from the sky'?
GEM–E3 and Regional GEM-E3	Value Added Taxes Indirect Taxes Direct Taxes Environmental Taxes Production subsidies Social Security Contributions Import Duties Foreign Transfers Government Firms	Government consumption by product (By Fixed coefficients) Government investment by branch Transfers at exogenous rate per head	N Y in regional version (Federal to regional transfers endogenous)	Y (Fixed / flexible closure)	N
EPPA	Employers' social contribution Employees' social contribution Personal income tax Corporate income tax Subsidies on production Taxes on production Subsidies on products VAT	Government consumption of public services, education, health, social work Unemployment benefits Other transfers Subsidies	N	N	N

	Receipts	Spending	Multi–Layered?	Deficit possible?	'Manna from the sky'?
Greenmod II	Value Added Taxes Indirect Taxes Direct Taxes (personal / corporate) Environmental Taxes Taxes on investment goods Social Security Contributions Import Duties Foreign Transfers	Government consumption of public services, education, health, social work Unemployment benefits Other transfers Subsidies	Y	Y (assumed fixed)	N
Mayeres (1999)	Labour income / capital income tax Excises, VAT Externality tax	Poll transfer Subsidies Transfers to ROW Government consumption Capital services	N	Y (assumed fixed)	N
CGEurope	CGEurope does not include a government sector				Y
RAEM 2.0	Labour income tax	Unemployment benefits	N	N	Y
RAEM 3.0	Social security contributions, corporate income taxes, Excise, VAT and other consumption taxes, production taxes, income taxes	Consumption and production subsidies, commodity demands, transfers to EU, transfers to households, unemployment benefits	N	Y	*(no policy applications yet)*

	Receipts	Spending	Multi–Layered?	Deficit possible?	'Manna from the sky'?
REMI	Social Security contributions Taxes (aggregated)	Government consumption (aggregated) Transfer payments (aggregated)	Y		Y
MMRF-Green	Commodity taxation by 5 expenditure categories Direct taxation (labour income, non–labour income, others) Agricultural production tax Land tax, rental property tax, stamp duties on property transactions Tariffs Interests received	Subsidies Interest payments Current and investment expenditure Personal benefits (disaggregated?)	Y (Commonwealth to state transfers endogenous)	Y (Fixed / flexible closure)	N
RELU	Income tax	Unemployment benefit, other transfers to housholds	N		N
Mobilec	Mobilec does not include a government sector				
NEMESIS	Income Taxes Social Security Contributions VAT, Indirect taxes on consumers and industries	Intermediate consumption Social Security benefits	N	Y	N

When debt is included, GEM–E3, GreenMod II and MMRF-Green allow different closure options for the government budget: either the deficit is kept flexible, or the deficit is kept fixed, and some tax shifter is made endogenous. The model of Mayeres only allows for fixed deficits / surpluses.

Concerning the range of the government instruments that are included, we give an elaborate overview in Table 6. We confine ourselves here to noting that the degree of detail ranges from none (there is no government sector in CGEurope) over sparse (just one income tax, unemployment benefit in the RAEM 2.0 model) to very detailed (MMRF–Green). A common feature seems to be that the NEG models pay less attention to the modelling of the government sector compared to the conventional environment and transportation oriented models (with the notable exception of the REMI model).

We will spend more time considering the representation of the vertical structure of government, given the importance of the regions and communities in our country. We consider GreenMod II and the regional extension of GEM–E3 to Belgium by Saveyn and Van Regemorter (2007), since they both model the Belgian case. We pay particular attention to the division of competences and instruments between the regions and the federal government and the transfers between governments. These distinctions are made to capture the so-called vertical externalities between different government levels, where the policies of one layer (e.g. a unilateral move of one region) affect tax revenues of the federal state, and vice–versa. The regional GEM–E3 model has been used to explicitly calculate the vertical effects of different climate policies. The analyses done with Greenmod II do not yet explicitly consider such externalities, but the model is also able to do so.

In GreenMod II the federal government levies the VAT, excises, other consumption taxes, personal income taxes, corporate taxes, social security contributions, taxes on production and taxes on investment goods. Transfers in GreenMod II are 'other transfers' (including pensions) and unemployment benefits. The federal government consumes public services, education, health and social work: these goods are produced by the production sector. Regional governments collect taxes on private consumption, capital use and production (The inheritance taxes thus are not included). They also levy an additional percentage on the personal income taxes. The regional governments give transfers to households and consume education services and public services. We note that the French community is modelled as an autonomous entity, whereas the Flemish community is lumped together with the Flemish region.

Saveyn and van Regemorter (2007) use the following distribution of tax revenue between federal and regional (including municipal) governments, when constructing the social accounting matrix.

Table 7: Breakdown of tax revenue accruing to different government levels in Belgium (before redistribution) according to the regional GEM–E3 model

	Federal Government	Regional Government
Direct taxes	79 %	21 %
Indirect taxes	64 %	36 %
Subsidies	0 %	100 %
Duties	100 %	0 %
VAT	100 %	0 %
Government Firms	50 %	50 %
Social Security	80 %	20 %

Source: Saveyn and Regemorter (2007)

Also important is the constitutional transfer from the federal level to the regional level. A large part of the regional budget is provided by transfers of part of the fiscal revenue from the federal government, notably part of the personal income tax and the VAT. This transfer is indexed with the regional consumer price index (CPI) in GreenMod II. The regional GEM–E3 model lets the *size* of the transfer vary according to real GDP growth (91% of GDP growth with a minimum growth rate of 2%) and the number of students in each region (proxied by the number of inhabitants), the *distribution* between communities varies according to the share of revenue from each region, the share of each region in total student numbers and other parameters.

We close this discussion by noting that the Belgian federal model is until now a so–called expenditure federalism, with few competences for regions on the taxation side, but important competences on the expenditure side. These expenditure competences may be important for transportation purposes. In 2000 the federal government spent about 4577 million euro on transportation. The lower governments' transportation expenditure amounted in the same year to some 4907 million euros (Nautet and Vuidar, 2006).

2. Policy

After describing how the government sector enters the model, we will go into more detail about how government instruments are actually used by the modellers for policy simulations.

In this respect one quite important remark is appropriate. Some models use policy simulations, which enter the model as 'manna from the sky' (or 'leak to nowhere' if the instrument in question is tax). For example, CGEurope simulates European investments in transportation, as well as social marginal cost pricing scenarios. In both cases it is unclear where the money for these investments comes from, or where the revenues of the pricing policies are reallocated in the economy. RAEM 2.0 and RUBMRIO also simulate infrastructure projects, without specifying where the funds for these investments are raised. These policies thus take place outside the budget of the government, which is subject to some closure rules. This essentially violates the general equilibrium requirement that all money flows should end up in and originate from within the economy.

The policy issues considered in the applications of the NEG models of CGEurope, RAEM 2.0 and RUBMRIO are improvements in transport possibilities. In RAEM 2.0 these are measured as reductions in the (monetary) cost of transporting goods and the search cost of finding goods. Next to these the cost of commuting is also considered. Any improvement in transportation will result in changes in the transportation cost matrix. An explicit distinction between time costs and monetary costs is not made. The CGEurope model also considers the lowering of transport costs, including both the cost of freight and the cost of business travel. (CGEurope II also considers long distance passenger travel)

The transport model of Mayeres conducts simulations whereby an exogenous increase in government consumption is accompanied by an increase in taxation, either through peak load pricing, fuel taxation, labour taxation or a lump sum tax. A decrease in public subsidies to transport is also considered. The aim is to compare the marginal social costs of the different tax instruments, from which possibilities for welfare improving tax reforms can be derived. RELU is used to estimate the land use and general economic effects of a cordon toll, in combination with a more detailed transport model.

The GEM–E3 model allows for the flexible introduction of environmental taxes, permits and technical standards. Standards of energy use can be imposed on countries, sectors and on individual goods. Taxes (on emissions, energy content, depositions and damage) can be set as a fixed rate, or as an endogenously varying amount, given a certain quantity restriction. Markets in permits can be specified, in which permits are allocated on the basis of grandfathered rights. Auctioning of permits is not modelled since it is equivalent to a tax. Various kinds of permits can be introduced, ranging from undifferentiated emission permits to regionally differentiated immission permits.

The same amount of flexibility characterises the EPPA model, which allows for constraints on different regions, sectors or greenhouse gases. This flexibility allows for the calculation of several sector / greenhouse gas specific prices.

In describing the emission permit markets, different departures from the Walrasian case can be considered. In the perfectly competitive market profit maximisation by firms (including the value of permits that are not consumed) will lead to a permit price equal to the marginal product of the polluting input. However, different imperfections can be modelled. First, firms selling on the permit market may have market power, so unless firms exactly consume their permits, the market will be inefficient, since price and marginal cost will not be the same anymore. A second departure from the Walrasian market is the introduction of market makers, who cause a bid and ask spread. Again, inefficiencies arise since prices of suppliers and demanders are not equal. The same inefficiencies arise when transaction costs are introduced. The EPPA model, used to analyze the European Trading Scheme, does not include any transaction costs due to setting up registries or due to market makers, but this is not considered to be a problem, since the changes to the overall conclusions of introducing such costs are not expected to be large. (Reilly and Paltsev, 2005). The GEM–E3 model has been extended to allow for market power. (Pratlong et al., 2004)

In case of multiple pollutants, it may be possible to model trade among the different pollutants. In this case a trading rate must be specified to express all the pollutants in terms of a reference. The EPPA model allows for such a unified market, by expressing all gases in carbon–equivalent. Markets can also be organised in terms of each pollutant. In this case, marginal productivities of pollutants are not equalised, as in the case of a unified market.

In an intertemporal framework, one can consider the possibility of permit banking. In this case, firms can store their permits in one period to be used later. Banking will take place if the amount of permits allocated at the outset is sufficiently high. The Greenmod team has considered introducing banking in the model.

One other possible extension may be the introduction of uncertainty in the permit market. In such a case, firms may benefit from the purchase of derivatives such as futures, forwards and options. It is not sure whether any of the models considered have specified derivatives markets in their model.

G. Modelling transport decisions

1. Modelling of transport/supply production

The transport sector is somewhat special, when treated in economic modelling. First of all, it is quite heterogeneous. For example, there are both consumers and firms that use inputs of the transport sector, but with different purposes. Consumers will be the major users of passenger transport, which can be private transport, supplied by their own vehicles and fuels. Or they can buy access to a specific transport mode, ranging from different transport modes and supplied by different firms, including public enterprises. Firms will be preferential users of freight, influencing the transport costs and the economic structure of the country. They also use passenger transport as an input (business transport).

Table 8 summarises the discussion.

Table 8: Modelling transport decisions

Model	Freight& passenger transport?	Own/ purchased transport?	Trans-port sector?	Mar-ket struc-ture	Iceberg assumpti on?	Transport modes	Trips purposes/ goods types?	External Model?
GEM-E3	Y	Y	Y	User choice	N	N	N	N (externa lities by ExternE)
EPPA	N Household/Firm consumption of transport separately	Y	Y	PC	N	Water, air, other	N	N
NEMESIS	Y	Y	Y	MC	N	Private car, Rail, air, public road, other	N	N
Green-ModII	N	N	Y	OC	N	Land, water, air	N	N
MMRF-Green	Freight transport services are sold indirectly as margins on flows of goods and services.	N	Y	PC	N	Road and other Substituti on effect road & rail	N	N
CG-EuropeI	N	N	N	N	Y	Trans European Transport Networks	N	SCENES
CG-EuropeII	N	N	Y	PC	Y	see CG-EuropeI	N	SCENES
Mayeres (1999)	Y	Y	Y	PC	N	Road, rail, inland navi-gation	N	Y for externali ties
EDIP	Y	Y	Y	PC	N	4 modes	Y (3 distance classes)	TRE-MOVE TRANS-TOOLS

Model	Freight& passenger transport?	Own/ purchased transport?	Trans-port sector?	Mar-ket struc-ture	Iceberg assumpti on?	Transport modes	Trips purposes/ goods types?	External Model?
RAEM	Y	Y	Y	PC	N	Road	Shopping, education, commuting & other	SMART
REMI	-	-	N	-	-	-	-	-
RELU	Y	N	N	N	-	Road	Cost disaggre-gated by trip purpose, OD pair and skill level	-
RUBMRIO	N	N	N	N	-	Road		-
Mobilec	Y	N	N	N	-	Road	Consump-tive mobility (shopping, education, leisure,…) and commuting	-

Note: PC = perfect competition, MC = monopolistic competition, OC = oligopolistic competition

The first choice to make is whether the model will incorporate a separate transport sector or not. Models that focus more on trade flows and spatial economics, such as RUBMBRIO, RELU and Mobilec, do not have a separate transport sector and only incorporate an exogenously given transport cost. CGEuropeI only models transport costs and does not consider a separate transport sector, while CGEuropeII uses a representation of a transport sector, but still considers transport costs in a simplified way.

When models use a distinct representation of the transport sector, it can be further disaggregated by transport mode. GEM-E3 only considers one aggregate transport sector. Other models make a distinction between road transport and other transport (MMRF-Green), split up transport production in land, water and air transport (GreenmodII, EPPA) or even consider road, rail, water and air separately (CGE model of Mayeres, EDIP).

Most models represent transport production at the national level. Only some SCGE models, like RAEM have the representation of transport production on the regional level. Such representation allows one to look at specific effects of economic changes on the region-specific transport sector, but it makes the model more complicated.

The production technology of the transport sector will mostly be similar to the other sectors in the economy. This means that at the first level of aggregation Leontief will be used (to combine the KLE bundle with intermediate inputs) and at the other levels CES production technology or Cobb-Douglas (RAEM). At the lowest nest, different types of fuels are combined using (in most cases) a CES production function.

An example of a durable and non-durable linkage in the case of own-produced transport (cfr. section II.C.3) is used in the CGE model of Mayeres, EDIP and GEM-E-3.

An example of a durable and non-durable linkage in the case of a transport model is where a car vehicle (durable good) is linked to a minimum amount of fuel used when buying the good (non-durable linkage), while consumption of 'own passenger transport' with this car requires an input of fuels (non-durable consumption). GEM-E3, Mayeres (1999) and EDIP employ the concept of a variable expenditure function with quasi-fixed durable goods (car vehicles) as arguments in order to derive a demand system for nondurable goods (fuels) in prices of the non-durables, in the stocks of durables and in variables expenditure.

The market structure for the transportation sector is often modelled to be in perfect competition, like EPPA, CGEuropeII, MMRF-Green and even RAEM, but is modelled as a sector in oligopolistic competition in GreenModII. The choice for perfect competition for the representation of the transport sector is often guided by a lack of data.

None of the models considered here allows for an analysis of policies towards company cars that are also used for private travel.

2. Modelling of transport demand

When modelling the transport sector and transport decisions, many models make a distinction between passenger transport and freight transport. The distinction is logical, as passenger transport would normally appear in the consumption decisions of households, while the cost of freight transport will generally be a part of the cost function of firms. It should be noted however that firms also use business transport as an input.

In the modelling of freight transport, the transport service inputs are coupled with the inputs of the transported good. This can be done by using a Leontief approach, where the price of the transport service is added to the price of the transported good $p = p_g + A.p_t$, where A is some Leontief factor and p_g and p_t stand for the price of the good and transport service respectively.

Another way to do this, is to use a tax representation of the transport service, this means that the price becomes $p= p_g(1+A.p_t)$.

Private passenger transport is a part of the consumption decisions of the households. This is done via integrating transport services into the households' utility function. The models use either the CES or Linear Expenditure System (LES) representations of the households' utility function. CES functions make it possible to use complex nesting structures, for example Mayeres (1999) uses 8 levels of direct utility of transport to consumers, where transport appears at the third level, making that the transport utility itself has 5 supplementary levels. (Peak and off-peak use, mode of transport, type of fuel, committed and supplementary mileage and diverse services at the lowest nest).

The EPPA model distinguishes 'transport' and 'other consumption' on the second level and then splits up transport into purchased transport and private car use. Private car use is split up into fuel use and a 'transport services nest'. The split-up into private transport and own-transport generates more realistic results, as they will generally not have the same elasticity of substitution. Both own-produced and purchased transport can be linked to different types of intermediate inputs, like fuels and services auxiliary to transport.

An alternative to the CES/LES approach is to use a 'trip generation' function. The generation of passenger trips in RAEM, with the exception of commuting, is done with a generation-distribution model, where the distribution model follows the structure of a constrained gravity model (see also the PLANET model). Outputs of the corresponding service sectors are used as attraction factors for the passenger trips. For example, a region with a high level of education production attracts more education trips. Higher transport costs between two regions lead to a lower number of trips between this origin-destination (OD) pair, but does not influence total number of passenger trips. While this approach can be used to derive the number of trips, it is less appropriate to derive the number of pkm.

Most of the models do not take into account different trip purposes. RAEM is an exception. In RAEM the attractions for the generation of the commuting trips are the labour endowment in the region of origin and the labour demand for labour in the region of destination. The amount of commuters is calculated through a 'coupling' function, using the generalised transport costs. When the transport cost increase the amount of commuters decreases exponentially.

Mayeres (1999) and EDIP are good examples of how complex transport decisions can be incorporated into a CGE model. In the EDIP model both households and domestic sectors use transport services in their consumption and production activities. Transport is subdivided into transport modes (road, air, inland waterways and air), three distance classes (long, short and urban) and 14 main vehicle categories. Each type of transport service is associated with the particular after tax price, which includes VAT taxes and other taxes. Public transport and freight transport services are produced by several national transport sectors. These sectors use labour, capital and commodities, for example fuels and vehicles, as inputs to their production. Passenger transportation by car is produced by the households themselves using fuel and car vehicles. In order to own a passenger car vehicle a household has to pay the car ownership costs, which include different types of taxes, such as registration taxes.

3. Modelling the costs of passenger and freight transport

The share of transport services used per unit of the transport good and the initial level of transport costs are usually based on the calculations of an external transport model or on a transport survey/statistics. This means that in order to transport one unit of good between a pair of regions, a fix amount of transport service (determined by the external model) is used. If a model evaluates a change in infrastructure, for example the widening of a road, this measure is implemented via a change in the fixed amount of transport services used per unit of the transported commodity.

GEM-E3 and MMRF-Green use transport costs from statistical sources and databases. CGEurope uses the outputs of the SCENES transportation model. The total transport costs used in CGEurope are calculated as the sum of distance-related costs and 'virtual' costs of impediments such as frontiers, language changes, bureaucratic formalities and so on. Logistic costs involved in trading at a distance are reported to be much more important than simple transport costs, and have to be calculated separately. The SCENES model has no network-elaborated intra-zonal element, or local transport/local network aspect. This means that local congestion-related costs are excluded from the total transport costs.

Calculation of the transport costs for RAEM was made by the SMART model, but other models can be used too, if transport costs are supplied in the right format.

EDIP uses the information from supply and use tables for the representation of transport and trade costs in the model. The shares of transport by distance type and by particular transport mode are calculated based on the outputs from TREMOVE model.

Some models, like CGEurope, model transport costs using the Samuelson iceberg assumption (1952). This means that a certain amount of the composite tradable, when transported from one region to another region, is used up ('melted') when delivering this good to that region. In modelling practice, this means that there is a fixed price increase τ for the price of good in region *i*, when shipped to region *j*, expressed as $p_j = (1+\tau)p_i$. Of course, this means that the relative prices of the goods in this region, will always be $(1+\tau)$, meaning that there is no variability in relative prices. This also means that transport is produced with the production function of the good that is being transported.

The iceberg assumption simplifies modelling a lot, but it may be unrealistic, especially for modelling the service sector and for financial sectors, in particular. One feature of the iceberg assumption is that a decrease in the transport cost may actually lead to a decrease in production, due to the lower price of the good.

Therefore, many models do not use this iceberg assumption. Instead, models express the transport cost as a mark-up over prices, often produced by a separate transport sector. As the transport sector uses different factors of production or some factors of production with a different degree of intensity, the relative price does not need to be the same. Nevertheless, the more similar a sector is to the transport sector, the better will be the approximation of the iceberg costs (Koren, 2004).

4. Modelling the external costs of transport and their impact on transport decisions

Modelling the external costs of transportation such as congestion, noise and accidents is often not treated within the models themselves. For example EDIP uses the TREMOVE model to calculate these external costs of the transport sector. This model estimates the transport demand, the modal split, the vehicle fleets, the emissions of air pollutants and the welfare level under different policy scenarios. All relevant transport modes are modelled, including air and maritime transport. Other externalities, like noise pollution and traffic safety (road accidents) can be treated in TREMOVE, but in a simple way.

Mayeres (1999) is one of the only models that incorporate congestion inside the model. Environmental externalities, traffic safety and health effects of transportation have a separable effect on the consumer utility. Congestion has a feedback effect on utility and influences final transportation demand. Congestion is modelled using a congestion function.

H. Environmental aspects

1. Generation of emissions

The modelling of environmental aspects varies substantially with the model's purpose. Table 9 gives an overview for the models that consider environmental impacts. Extensive modelling of environmental effects is not done when the focus of the model is on land use, like RUBMRIO or RELU.

When a model assesses economic impact of mitigation strategies of global warming, the focus will be on greenhouse gas emissions (GreenModII, MMRF-Green). If the focus is more on the general environment and externalities, models can also incorporate substances with health effects and environmental damage other than global warming (see e.g., Mayeres (1999) and GEM-E3).

Even when models are modelling emissions, the purpose of the model does not need to be the same. Global warming concerns gave rise to a variety of economic models evaluating the effects of abatement policies on the global/local economy. The EDIP emissions/environmental module is less complex than the other modules, but EDIP focuses more on distributional effects between households and regions.

Many models focus only on air pollution. This is true for GEM-E-3, EPPA, NEMESIS, GreenModII, MMRF-Green. Almost all of these models have a more or less detailed environmental module for greenhouse gas emissions, acidifying emissions and other emissions with a proven health effect (such as small particles and ozone), but do not deal with local pollution and 'point' effects. This means that often pollution with a very local or transient effect, such as water pollution is not treated.

Emissions in GEM-E3 are differentiated by country, sector, fuel, and type of durable good. Inputs are linked to production and emissions for all energy conversions. Non-energy sources of emissions, like refinery and other processing are treated separately.

It is common sense that the emissions of a sector depend both on the type or the combination of fuels it uses, its production technology and characteristics specific for that industry. In MMRF-Green, emissions from combusting energy inputs are calculated as a certain share of the *output of sector s, using the fuel type f*. Non-combustion emission relate directly to the "activity" or the output of the industry. A similar way to treat the generation of emission can be found in EPPA and GreenmodII.

Table 9: Modelling the environmental aspects

Model	Emissions	'Blame matrix'	Special aspects of environmental module	Abatement curve?	External model used?	Fuel prices?	Production technology?
GEM-E3	Greenhouse gases (CO_2, CH_4, HCFC, PFC, SF6), acidifying emissions, VOC, PM_{10}	Y	- Behavioural, environmental and policy support module are used together to assess the effect of environmental policy. - Emission damages based on ExternE and follow-up studies	Y		- Modelled endogenously, by the PRIMES sub-module - Initial data provided by EUROSTAT	- Electricity in the LEM bundle - Fuels in the labour, materials, fuels bundle in the next nest - Energy-savings technology (improves energy productivity)
EPPA	Similar to GEM-E3, but more extensive modelling, adding aerosols (SO_x, black carbon, organic carbon) and other substances (NH_3, CO,..)	Y	- Backstop technology - Depletion model for natural resources - Capital vintages - Autonomous energy efficiency improvement	N	EPPA is part of IGSM; the other modules are a climate and ecosystems model	Modelled endogenously but can be set exogenously	- Focus on energy inputs, treatment of fossil fuels /nuclear/hydro/advanced generation/wind/solar - All energy inputs are perfect substitutes except wind/solar - Energy bundle split up in electricity and non-electricity input - Separate coal-oil bundle besides gas inputs

Model	Emissions	'Blame matrix'	Special aspects of environmental module	Abatement curve?	External model used?	Fuel prices?	Production technology?
NEMESIS	Similar to EPPA and GEM-E3, but more strongly linked to energy consumption	Y	Large scale energy demand module (NEEM), based on econometric estimations. Adding a variety of features and structural input for the model.	Y	Fuel price calculations within NEEM	Made by NEEM	Production process represented by cost-functions, having quasi-fixed factors, spill-over sources and variable inputs.
GreenModII	Focus on greenhouse gas emissions	N	Backstop technology	N	Micro-simulation model for distributional impacts of policies	Modelled endogenously based on initial dataset	- Energy part of KE bundle - Distinction between non-electricity (combustion fuels) and electricity inputs in energy bundle. - Backstop technology for natural gas and carbon-free electricity
GEEM-Alaska	Pollution that affects the modelled ecosystem	N	Ecological model, working separately from the CGE model	N	N	N	N

Model	Emissions	'Blame matrix'	Special aspects of environmental module	Abatement curve?	External model used?	Fuel prices?	Production technology?
MMRF-Green	Focus on greenhouse gas emissions	N	- Inter-fuel substitution in electricity (energy) generation by region - Endogenous take-up of abatement measures - Emissions by emitting agent (residential + industries), by state and by activity	N	N	Modelled endogenously based on initial dataset	- Energy is treated as consumption good - Model does not allow changes in production process that decrease emissions per input of fuels. - Model allows energy savings.
Mayeres (1999)	GHG and other pollutants with focus on Belgian transport sector.	N	- Focus on transport - Damages of emissions based on ExternE study and follow-up studies - Impacts on different household types	Y	N	Endogenously calculated	- Distinction between energy for transport and non-transport. - Different fuel types - Durable/non-durable link - No endogenous technology representation
EDIP	Emissions of all industrial activities and road trafficl	Y	Impacts on different household types	Y	TREMOVE TRANSTOOLS	- Endogenously calculated - Input from TRANSTOOLS and initial datasets	- KLE bundle with separate energy bundle - Energy bundle split up in electricity and non-electricity inputs

In GreenmodII, but also in other models, the production sectors and production technology of the sectors are split-up in three types. The first nesting structure is used for the minerals & quarrying, nuclear & non-nuclear electricity, refining sectors. These are sectors that transform raw energy materials to energy used by other firms. The second nesting structure is a general nesting structure, similar to other models. The last nesting structure is used for agriculture and incorporates input of natural resources.

The modelling of the production technology of a sector can influence how emissions are modelled. For example it is assumed in most models (like in GEM-E-3), that the use of energy inputs can be traded off against higher capital inputs. Less energy inputs mean lower emissions, but paid at a higher capital investment, making the output more expensive. Often, nested CES production functions are used to model the substitution between capital and energy inputs or between different types of energy inputs or types of fuels. The nesting structure of the model both for production as for consumer utility can be quite different between models. Treating production, many models have a KLE bundle at the first nest, Value-Added and Energy at the second nest and then different types of energy in the following nests. At this level there is mostly a distinction between electricity and non-electricity output (combustion fuels). Here we should add that using the *CES functional form* here, supposes that the *substitution elasticity is the same for each fuel.*

Other, indirect forms of substitution are used within MMRF-GREEN for emission reduction. Inter-fuel substitution in electricity generated is handled using the "technology bundle" approach (see Hinchy and Hanslow, 1996). In the current version of the model, five power-generating industries are distinguished in each region based on the type of fuel used. There is also a separate end-use supplier (Electricity Supply). The electricity generated in each region flows directly to the local end-use supplier, which then distributes electricity to local and inter-state users. The end-use supplier can substitute between the five technologies in response to changes in their production costs. For example, the Electricity supply industry in NSW might reduce the amount of power sourced from coal-using generators and increase the amount sourced from gas-fired plants. Such substitution is price-induced.

2. The impact of technological progress on emissions

Many of the elements of the technological progress will be treated in the paragraph on R&D and technical progress (Section II.J.2). Here we will cover the aspects of technological progress that have a direct effect on abatement decisions, mitigation strategies and emissions.

Technological progress can increase the energy efficiency of the economy and lead to partial decoupling of economic growth and its burden on the environment. It usual to model these dynamic processes by means of exogenous time-trends applied to the input coefficients of energy or fossil fuels. In EPPA this is called the AEEI or 'Autonomous Energy Efficiency Improvement'. This represents the non-price induced, technologically driven changes in energy demand and is imposed exogenously. The model also includes an exogenous set of productivity factors describing the evolution of the emission coefficients for non-CO_2 greenhouse gases.

In order to incorporate of new technology and its environmental effects, the extended model version of GEM-E-3 uses the term "energy savings". This term indicates technology that improves energy productivity. Producers evaluate investment in energy-saving technology trough an inter-temporal marginal cost-benefit analysis. This is modelled as an additional demand for goods (for example equipment). Consumers can choose between two classes of durable goods: ordinary ones and energy efficient goods (advanced technology), at a higher price.

MMRF-Green uses a fixed relation between the fuel-usage in a specific process and the amount of emissions. The model does not allow any technological progress that changes this relation, for example by allowing coal-fired electricity producers to emit less CO_2 per tonne of coal burned. On the other hand, MMRF-GREEN does allow for input-saving technical progress. For example, the black coal electricity industry may reduce the amount of coal that it burns per kilowatt-hour of output. This sort of technical progress is imposed exogenously.

In NEMESIS, a distinction is made between demand related to the existing surviving equipment and new demand related to the net increases in energy needs and replacement of scrapped capacity. Regarding new energy demand, the model encapsulates the dynamic process of technological substitution in all sectors taking into account the technical and economic characteristics of the major available fuel/technology combinations.

A number of models, including EPPA and GreenmodII, include the representation of backstop technologies (cf. Section II.J). Backstop technologies are the technologies that might have a positive environmental effect, but are not competitive with 'dirtier' technology. The backstop technology is 'frozen' as long as it is not competitive. Increases in the price of conventional fuel can activate the technology. This means that the use of new technologies can change over time and that their use will become wide-spread. In EPPA 10 different backstop technologies are implemented, including the use of shale oil, energy from bio-mass, bio fuels (bio-ethanol), etc.

Besides backstop technologies, the EPPA model also includes a depletion model. In this way it can model the extraction of natural resources. All fossil energy resources are modelled as graded resources whose cost of production rises continuously as they are depleted. The resource grade structure is reflected by the elasticity of substitution between the resource and the capital-labour-materials bundle in the production function. Production in one period is limited by substitution and the value share of the resource: the technical coefficient on the fixed factor in the energy sector production functions. The resource value shares are determined and they represent the key differences among regions and fuels (using cost of capital, labour and materials bundle and value of the resource).

The use of capital vintages (cf. Section II.B.1) is another tool often used in environmental models. By implementing capital vintages we can track the capital through time: 'recent capital' can be subject to energy efficiency improvements and is more mobile, while older 'dirty capital' will not improve.

In most models the fuel prices are fixed exogenously based on an initial dataset or a forecast of prices (provided for example by the OECD or IEA).In EPPA the user has an option to determine fuel prices endogenously, by using the depletion model and the various demands for energy inputs in the economy. In EPPA countries are allowed to trade energy inputs and their preferences with respect to own and imported energy are represented using the CES function with an Armington elasticity of substitution.

The fuel prices in GEM-E3 are determined using an energy sub-model that is a simplified version of the PRIMES model. The original data for the model were mainly supplied by EUROSTAT. The energy sub-model in GEM-E3 takes as given the demand of sectors for energy products and determines energy prices and the fuel mix that meets this demand. This information is then used in the optimisation decision of the economic agents who decide upon the energy demand at the new iteration. In equilibrium prices and quantities used by both models are equal.

The NEMESIS energy/environment module is a large scale energy demand module (NEEM) that simulates the formation of prices on the energy market and estimates the quantities demanded by the main energy market actors. It includes an aggregate energy supply part in order to enable the calculation of overall energy balances per country and incorporates energy-related greenhouse gas emissions, environment oriented policy instruments and emission abatement technologies. It combines the NEMESIS activity forecasts with demographic and structural inputs as well as fuel consumer prices to derive aggregate energy consumption functions defined by sector (industry, tertiary sector, households, transport). Long-term and short-term price effects are accounted for separately.

GEM-E3 contains an interesting split-up in its environmental module. The behavioural module includes the choice of abatement technologies by consumers and firms. The abatement curves for the firms are based on bottom-up engineering data for Germany. The results for Germany were extrapolated to the other countries in the model. Abatement decisions of firms in GEM-E3 are explicitly modelled through a cost-benefit assessment of the investment in abatement, compared to the price of permit or tax.

MMRF-Green does not incorporate the full representation of the abatement curves, but incorporates instead point estimates of how a higher carbon tax increases abatement of a firm. This endogenous uptake of abatement measures is most important for the agricultural sector.

In EPPA abatement costs are endogenous, but it does not use the explicit representation of an abatement curve.

Besides a behavioural module, GEM-E3 uses an environmental module and a policy module. The state of the environment is determined by (i) calculating emissions of air pollutants from economic activities, (ii) determining the transportation of these pollutants between countries and (iii) assessing the damages from the pollutants in monetary terms.

When treating pollution between countries/regions, we should take into account that the place of emission of the pollutant does not need to be the place where the damage of the pollutant is experienced. Pollutants can be transmitted by wind or rain, remain inactive until triggered by a specific chemical reaction or only have visible effects when crossing a threshold value in a specific region. To account for these effects, a 'blame' matrix can be used. This matrix, similar to an origin-destination matrix, relates the emission of the pollutant of one country/region (or more detailed, an industry in one country) to pollution in another country/region. Calculating this blame matrix inside a CGE model is much too complex, so a blame matrix has to be provided exogenously from a separate model, based on scientific research. For example, the blame matrix for the EDIP model was built based on the RAINS/GAINS model of the IIASA.

3. Impact of emissions

The majority of the models use a separable utility function to account for the influence of environmental damages on the households' utility function[4]. This means that the behaviour of the consumer is independent from the environmental damage. The 'dis' utility created by the pollution is subtracted from the utility of consumption. Emissions can lead to several kinds of damages, not only to the ecosystem, but also to public health and infrastructure. The monetary evaluation of emission damages Mayeres (1999) and GEM-E-3 were based on the ExternE study and its follow-up studies.

EPPA is actually a part of a larger model, the IGSM model. This model contains a climate model and a terrestrial ecosystems model. The effect of 'anthropogenic' emissions is assessed using these sub models.

GreenmodII uses a separate micro-simulation model of the Belgian economy to look at the distributional effects on households. This model was based on the work of Robillard et al. (2001).

[4] Some models relax this assumption, see Section III.E.

It was constructed using the data from the Belgian household budget survey from 1997-1998. The dataset covers the 3 regions of Belgium. A micro-simulation model offers the researcher an interesting tool to look at the distributional effects of policy shocks.

In EDIP all production activities and in particular the transportation activity is associated with emissions and environmental damage. Environmental quality is one of the main factors of the households' utility function. Changes in the levels of emissions have a direct impact upon the utilities of the households. The welfare of each household type (population group) in the EDIP model is calculated as the 'equivalent variation measure' and depends upon consumption of commodities, consumption of leisure and the level of environmental quality.

Probably the most worked out environmental impact modelling is to be found in the GEEM Alaska model. It explicitly takes into account an ecology module, working side by side with a (simple) CGE model. GEEM is applied here to an oft studied marine ecosystem comprising Alaska's Aleutian Islands (AI) and the Eastern Bering Sea (EBS). The ecology model tracks the energy flows in the ecological module, first originating from the sun and then diverting itself trough the ecosystem to (phyto) plankton and plants to a variety of animals. The ecology module works somewhat similar to conventional CGE, but here demand and supply originate from "energy prices". The biggest difference with the economy model is that in this case, there is no real exchange: the prey in the ecology model does not receive its energy price; full energy is taken up by the predator. As in economic CGE models, the prices play a central role in each individual's maximisation problem, because an individual's choice of prey will depend on the relative energy prices it pays.

I. Welfare and policy evaluation

In evaluating different projects, there are two basic strands in the modelling practice. Most are very close to the Cost Benefit Analysis method, and thus try to make a full account of all effects on welfare. Changes in consumers' utility are then expressed in monetary terms. External effects are also expressed in monetary terms, usually on the basis of external studies. Off course, this will only resemble CBA when all effects are accounted for, which is not always the case, as we have seen in previous paragraph. Some models indeed fail to account for sources of investments or destinations of revenues. Other models, such as Mobilec and NEMESIS will depart from the CBA approach and present more specific project impacts, such as GDP or employment changes.

The CGEurope models, focusing on the cohesion between some 1372 regions, calculate the percentage gain / loss in equivalent variation of consumer utility per region. They calculate an additive social welfare function with constant relative inequality aversion. From this function, a measure of the change in welfare inequality is calculated: the extent to which the aggregated percentage gain in welfare has to be adjusted downward or upward due to rising or falling inequality, respectively.

Outcomes in RAEM 3.0 are evaluated according to equivalent variation. Next to this welfare measure, a whole range of economic indicators can be calculated.

In performing policy simulations, the REMI model first calculates the direct effects of a wide variety of policy measures and translates this into variables within the model (such as travel time, labour productivity, supply of skilled workers). In a second stage the total output effect of the policy change is calculated. Outcomes are presented as the GDP change by production sector per 100 euro of investment, and projects are evaluated according to present value of cumulative GDP. Change in employment is also presented.

We found the most extensive treatment of welfare evaluation for the environmentally orientated models in the GEM–E3 model and the model of Mayeres. Welfare in GEM–E3 is calculated as the consumer's utility function, complemented with an environmental welfare index, which is based on the valuation of damage generated by policy. The welfare impact by country is aggregated by a constant relative inequality aversion function. Next to welfare, the present value of equivalent variation is calculated. 'Damage' is described as a function of the incremental change in deposition/concentration of a pollutant. Damages considered are damage to public health (morbidity and mortality), global warming and damage to ecosystems. The valuation of this (incremental change in) damage is based on various willingness–to–pay estimates taken from the ExternE project and its follow-up projects.

The EPPA model seems to use only economic cost measures, such as GDP, Equivalent Variation to evaluate the impact of different climate policies. An interesting discussion of the proper use of different economic cost measures (without including a valuation of environmental gain), with applications using EPPA, to evaluate the implementation of environmental policy is found in Paltsev et al. (2004).

In the Mayeres model, the consumer utility function takes into account not only purely economic elements, but also the level of congestion, accidents and pollution. The last two impacts enter utility in a separable way, while congestion has a feedback effect on consumer behaviour. From this utility function, the equivalent variation of policy changes is computed.

For the case with different income categories, a CRIA (Constant Relative Inequality Aversion) welfare function is computed. The change in welfare is computed as the social equivalent gain, obtained as the factor which should be added to each household's equivalent income before the reform to produce a level of social welfare equal to that obtained in the post reform equilibrium. The change in inequality is measured through the Atkinson–Kolm index.

In RELU the welfare function includes a random i.i.d. Gumbel parameter. To enhance understanding on the different effects, welfare is decomposed into terms representing changes in toll revenues, real estate value, wages, prices, rents, commuting costs and the cost of shopping.

J. Dynamics and technical change

1. Dynamics

There are two broad ways in which applied CGE models incorporate dynamics, depending on the way agent's expectations are treated. One is to introduce forward looking expectations, so that agents maximise their intertemporal objective functions taking into account future developments. Another is to have agents' expectations depend on past or present parameters, called static of backward looking expectations. In this case a recursive dynamic structure can be preserved, with the economy consisting of a sequence of equilibria. Between these equilibria a selection of variables are dynamically updated, either exogenously or endogenously. Due to their computational simplicity, the last way is overwhelmingly present among the models we reviewed. In this section we concentrate on the way saving and investment behaviour is treated in the various models. Saving is usually modelled in a very simple way, as a fixed share of households' income. The exception to this rule is GEM–E3, who allow for endogenous saving based on consumer utility maximisation. In this model the saving rate depends on the interest rate and consumer prices.

The treatment of investment behaviour is more interesting. In general, aggregate investment mimics domestic saving (sometimes supplemented by foreign capital), so that aggregate capital follows a permanent inventory–type path. Equality of savings and investment is then determined by a closure rule. However, it is the breakdown of investment by sector which is worth some more paragraphs. The way in which sectoral investment is endogenised, is crucial to the dynamic adjustment path of sectoral capital in response to shocks altering the rate of return. We found two broad ways of determining a sector's investment behaviour. One is the treatment of physical capital accumulation as explained in Dixon and Rimmer (2002), which forms the basis of the MONASH recursive dynamics. This way of modelling is used by RAEM 3.0, EDIP, GreenMod II, and MMRF–Green (even though the MONASH model on which MMRF–Green is based, allows for forward looking expectations as well). Another approach for modelling investment is found in GEM–E3.

In GEM–E3, firms must conjecture on the demand for capital in the next year for which they need to form expectations on future product prices and future demand. For future prices firms base their expectation on the current price level. Future demand is derived by taking into account the expected growth rate of the sector. At the moment it is unclear how these expected growth rates are determined. When expectations on the future need of capital are formed, the firm compares this with the current stock of capital. Investment is determined by subtracting future needed capital by current capital minus depreciation. However, the process of adjustment is slowed down by the inclusion of a partial adjustment parameter in the equation determining investment.

The MONASH dynamics assume that sectoral capital is supplied to the sector according to an inverse logistic function, relating the rate of return to capital to the proportionate growth of the sectoral capital stock. The idea behind such a relationship is that investors require a higher rate of return to their investment, if capital growth is already high. The function is constrained by a minimal and maximal capital growth, in order to keep the rate of accumulation at a realistic level. Minimal capital growth is usually the inverse of depreciation, maximal capital growth is set by the modeller (MMRF–Green uses the trend growth of the sector + 0.06, while RAEM 3.0 uses the trend growth + 0.064). In order to properly pin down this capital supply function, one has to estimate the historical rate–of–return of the sector, the trend capital growth, as well as assign a value to the derivative of the rate of return to capital growth. Data on individual industries are sometimes hard to come by, but MMRF–Green uses investment functions used in Australian macro models to estimate this parameter, which governs the curvature of the capital supply function.

Given this function, an expression for the rate of return must be found. The rate of return is taken to be equal to the present value of investment in the sector, divided by the cost of capital in that sector. The expression for present value naturally includes an expression for the value of investment, or the rental rate of capital, in the future. Static expectations, however, assume that investors use the current rate to conjecture on the future rental rate.

These two equations are then combined to determine an expression for sectoral capital growth, and sectoral investment using the simple perpetual inventory equation.

2. R&D and technical change

In reviewing technical change we consider the following questions, which are summarised in Table 10. Is technical progress introduced exogenously in the model, or is it endogenous? In which direction does technical progress work? This concerns the classic question of the neutrality of technical progress, whether it is augmenting the contribution of a production factor, whether it saves an input or whether it is just Hicks neutral total factor productivity (TFP) growth. Some models introduce features such as learning by doing, R&D spill-overs and backstop technologies. Note that we do not consider in this paragraph the price induced substitution of inputs, nor the decision to abate by firms. The former effect has been dealt with in the paragraph regarding producer behaviour (Section II.B). The latter is treated in the 'environment' paragraph (Section II.H).

Table 10: The representation of innovation and technical change

	Endogenous Technical Change?	Direction of technical change	R&D Spillovers?	Learning By Doing?	Backstop Technologies ?
GEM–E3	Y in extension	TFP Growth Input Augmenting	Y	N	N
EPPA	N	Labour Augmenting Natural Resource Augmenting Energy Saving	N	Y	Y
Greenmod II	N	Flexible	N	N	Y
MMRF–Green	N	Flexible	N	N	N
REMI					
Mobilec	N	TFP Growth	N	N	N
NEMESIS	Y	Flexible	Y		

Few models find it useful to endogenise technical change. Not surprisingly, the environmentally oriented models pay most attention to the representation of innovation, and a few of them have endogenised the innovation process, notably GEM–E3 (in an extension) and NEMESIS.

Some dynamic models allow for an exogenous representation of technical progress. In these models the Cobb Douglas part of the production function contains a scaling parameter which can be used to make some exogenous assumptions on the rate of TFP growth. This way of representing technical progress is quite coarse, without the possibility to represent biased technical change and the response of innovation to price and policy changes.

The MMRF–Green model gives the user the possibility to specify technical progress exogenously through a wide range of shift parameters, which gives the user some flexibility in introducing TFP growth or a combination of input saving changes. No allowance is made for inventions that might allow producers to release less of a pollutant per unit of energy consumed. If the model is used for historical simulations, parameters are estimated econometrically from historical data.

EPPA imposes exogenously the augmentation of labour and natural resources. The growth factor of effective labour is specified by a logistic function. Initial and terminal growth rates must be set exogenously. As energy is concerned, the EPPA model recognises the fact that historically countries have seen a drop in the energy intensity of their economies as their GDP grew. The causes of this drop have been widely debated, but in order to respect this historical experience, the input coefficients for energy and fuels are endowed with an exogenous trend, controlling the evolution of demand reduction factors that scale the production sector's use of energy per unit of output. For developed countries this trend is assumed to display positive growth over time, but for developing countries energy efficiency is first assumed to drop for a few decades before it is allowed to rise.

EPPA and Greenmod II are the only models allowing for the introduction of backstop technologies in energy production. These new technologies enter endogenously when they are economically competitive with more conventional types of energy supply. Competitiveness depends on endogenously determined prices for inputs, which in turn depend on depletion, climate policy and the general growth of the economy. For each new technology, a mark–up factor is identified, which expresses the cost disadvantage of the new technology versus the conventional one in the base year. This factor can be interpreted as the rise of the conventional energy price necessary to make the new technology competitive.

The adoption of new technologies is generally seen as a gradual process. To replicate this gradual penetration, and to avoid unrealistically rapid responses of the supply of new technologies to price changes, the EPPA model makes capacity expansion dependent on the endowment of a specialised fixed factor. This specialised factor is initially only available in small amounts, thus limiting the capacity that can be built initially. However, the endowment of this factor is made dependent both on industry output, as well as its stock in the previous period. Thus, as output gradually expands, the endowment of the fixed factor rises, and after a while it ceases to be a constraint on the industry's capacity. The intuition behind this mechanism is the existence of a learning by doing mechanism. Only by actually producing the new technology, the engineering firm is able to train new specialised staff able to operate the innovation. In EPPA, the function which governs this mechanism is parameterised based on observations of the ability of nuclear power to expand since its introduction.

In Greenmod II, two endogenous backstop sectors are modelled, but it does not deal with the issue of gradual adoption. Other technical progress can be imposed exogenously through scaling parameters in the production function.

As has been noted, only two models integrate endogenous technical progress and R&D. We will dwell a bit longer on how they operationalise endogenous growth.

For GEM–E3, the DYN–GEM–E3 project has elaborated an endogenous growth module, compatible with the constant returns to scale perfect competition assumption that characterises the basic version of the model (Kypreos, 2004). Six types of technical change are allowed for: Hicks neutral technical change (TFP growth) and biased technical change augmenting the 5 production factors: fuel, electricity, capital, labour and materials. To formalise biased change, each factor is expressed in terms of efficiency units. Efficient inputs are expressed as a CES function, whose arguments are inputs and the stock of input specific innovation. Hicks neutral change (quality innovation) is being formalised by expressing total output as a CES function with the stock of quality innovation and a CES composite out of efficient inputs as arguments. This yields a general specification, which allows investigating whether a change in the direction of innovation accelerates growth or whether crowding–out effects decrease it.

Then a market for innovation is specified. The demand side consists of demands for the 6 kinds of innovation by firms, taken from a producer's cost minimisation program. The demand for innovation is a positive function of the price of inputs (output in the case of Hicks neutral change), and a negative function of the price of innovation. Innovations are supplied by a perfectly competitive, CRS innovation sector. R&D is transferred to real innovation by the productivity of the research sector. The productivity of this sector is determined by two externalities. Through the general knowledge externality, the stock of general knowledge, intra– and intersectoral, national and international has a positive effect on the productivity of the research sector. The current stock of specific knowledge accumulated by the research sector has a negative impact on the productivity of the research sector.

The effect on R&D of different environmental policies, raising the price of energy, is tested and is found positive. The ensuing rise in biased innovation adds to the efficiency of the economy, thus dampening the negative GDP effects of stricter policies.

Where GEM–E3 is one of the first applied general equilibrium models to endogenise technical progress, NEMESIS aims to be one of the first macro econometric models doing the same.

The starting point of the endogenous innovation framework is the specification of a cost function with three variable inputs (labour, energy and materials) and two quasi–fixed factors (physical capital and R&D capital). From the cost function, demand functions for variable inputs are derived from Shephard's Lemma. Desired growth rates of both quasi fixed factors are derived from a dynamic programming cost minimisation program. The derived factor demands allow, next to the usual own and cross price elasticities, for spill-overs on the cost of each factor by the R&D capital stock of the own sector and 5 other groups of sectors (namely, office machines, electrical goods, chemical products, other equipment goods, and the other sectors lumped together). The relevant R&D capital stock for the spill-overs consists of domestic and foreign

R&D stocks, where foreign stocks are weighted with the share of the foreign country's stock in total world stock.

The R&D growth rate depends on input prices, output, the cost of R&D and the cost of physical capital.

We note that it is not clear from the documentation in our possession how NEMESIS has implemented its intention to also represent endogenous *product* innovation (as voiced in Fougeyrollas et al., 2000). This is of interest, since in a monopolistic competition framework endogenous product innovations would entail the endogenous expansion of product varieties.

III. State–of–the–art in theoretical modelling

After presenting a selection of current applied models, we wish to cover some of the recent developments in the theoretical fields. These may provide useful ideas which may be incorporated in a later stage. In turn, developments in the field of land use, endogenous growth and technological development, regional labour markets, ecological–economic modelling and the use of stochastic elements in CGE models are discussed.

A. Land use

A variety of modelling approaches are used for the analysis of land use change. In this chapter we focus on those models that are generally acknowledged in the recent literature as the most suitable for modelling contemporary complex land use systems.

Until a decade ago, the most frequently used models of land use change were statistical and econometric models, spatial interaction models and optimisation models (e.g. linear programming models). Nowadays, these models seem to be obsolete. Statistical models often suffer from problems like multicollinearity, spatial autocorrelation and violation of the linearity assumption. Econometric and spatial interaction models lack a sound underlying theoretical foundation, making their exploratory capacity very limited. The main criticism against the classic approaches to land use modelling is that several drivers of land use are not accounted for because the mathematical basis of the models (they need to be solved for closed-form analytical equilibrium solutions) makes them too rigid to cope with complex land use systems. In sum, they provide a rather simplistic treatment of land use.[5] For an overview and evaluation of these classical modelling approaches, and some references, we refer to Briassoulis (2000), Aspinall (2004) and Parker et al. (2003).

Recently new models have become available. Two major, spatially explicit, approaches can be discerned: models that are landscape-based and focus on patterns of change (so-called cellular

[5] As Briassoulis (2000) summarises in her excellent overview of land use models: "reality is so complex; land use change comes about under the influence of many macro and micro factors, acting and interacting within varying time frames. Land use change problems are essentially metaproblems. Therefore, the reduction and simplification of this real world diversity to serve the purposes of model building is extremely difficult. The result may be either a very crude representation of reality or, on the contrary, a very complicated model structure that is impossible to handle within the bounds of reasonable time and other resources available to answer practical questions. A second reason is that many theories are cast in abstract terms which make their operationalisation difficult. Abstract theories are, in part, a reflection of real world complexity and of inability, on the part of the theoretician, to disentangle the complex world and discover order behind the apparent chaos."

automata models), and models that are agent-based and focus on the underlying decision process[6] (Veldkamp and Verburg, 2004). The unit of analysis is thus either an individual pixel or an individual decision-maker. Both types of models acknowledge the importance of scale effects in studying spatial interactions (Evans and Kelley, 2004)

1. Cellulair automata based models

The cellular automata modelling framework is based on the theory of fractals and applies cellular automata concepts to model a variety of complex, dynamic, socio-economic and environmental phenomena (see e.g. Engelen, 1988; White and Engelen, 1993).

Engelen et al. (1995) define cellular automata as "mathematical objects that have been studied extensively in mathematics, physics, computer science and artificial intelligence (…). Tobler (1979) defined them as geographical models but they have only rarely been applied in human geography in the years since he proposed them. (…) A cellular automaton consists of an array of cells in which each cell can assume one of k discrete states at any one time. Time progresses in discrete steps, and all cells change state simultaneously as a function of their own state, together with the state of the cells in their neighbourhood, in accordance with a specified set of transition rules. Transition rules can be either quantitative or qualitative or both". A cellular automata model consists of: "(a) a cellular space, normally two dimensional, (b) a definition of the neighbourhood of a cell, (c) a set of possible cell states, and (d) a set of transition rules" (White and Engelen, 1994).

Cellular automata models have some important advantages over conventional modelling approaches because they can integrate macro- and micro- spatial and temporal processes, and because they can cope with complex real world systems, using theoretical assumptions that can be specified by the user.

A well known and widely used example of a cellular automata based model is SLEUTH (slope, land use, exclusion, urban extent, transportation, hillshade), which is used in an urban context. It combines an urban growth model with a model of land cover changes. SLEUTH is essentially a pattern-extrapolation model that comprises two phases: based on simulations of urban development patterns over an historic time period (first phase), it forecast these patterns into the future (second phase). Four growth rules (types of change in urban land use) are used for the simulations, and are applied sequentially during a growth cycle or year. The growth rules are defined through five growth coefficients (between 1 and 100), the values of which are derived during the calibration process in which different parameter sets are tested for their ability to replicate historic growth patterns. (Jantz and Goetz, 2005)

[6] For a discussion in an urban context, see Batty (2005).

Another example of a cellular automata approach at the regional level is given by Engelen et al. (1995). The model operates at two spatial levels: an upper (macro) level and a lower (micro) level. The iterative modelling process proceeds in four steps:

1) the basic geographic data needed by the upper level model is retrieved from the database, aggregated to the regions used in the upper level model and passed to it;
2) the upper level model calculates the values of the variables in each region and passes them to the lower level, the cellular model;
3) the cellular model allocates these values at a micro level, using – if necessary–more information from the database;
4) the results from the previous step are used to update the database, and the model returns to the first step for the next iteration.

The cellular automata approach is a discrete approach that is very flexible since (i) it can accept various specifications of the rules governing the conversion of land uses in the cells of the study area, (ii) it incorporates environmental and other considerations in the assessment of the potentials for change and (iii) it can be linked to higher level models as well as to GIS for more efficient use and manipulation of input and output spatial information. Some shortcomings of the model are that it does not consider the transportation system explicitly, it is based on stationary transition rules and therefore has limited ability to reflect feedbacks in the system under study, and the spatial subdivision assumed by the model (the cellular array and the magnitude of the cells) may not be congruent with the actual spatial formations which emerge under the complex interplay of the forces which drive land use change. (Parker et al. 2003; Briassoulis, 2000). Most of these constraints are addressed by a new generation of cellular automata based models, which are more flexible because they relax many of the assumptions of classic cellular automata theory (homogeneity of space, uniformity of neighbourhood interactions, universal transition functions). (Jantz and Goetz, 2005)

The main disadvantage of cellular automata models is that the units of analysis and the simulations do not match with the units of decision making. As Parker et al. (2003) conclude their review of this type of models: "In sum, cellular models have proven utility for modelling ecological aspects of LUCC[7], but they face challenges when incorporating human decision making". A recent and rapidly expanding group of models use individual agents as units of simulation. (Verburg and Overmars, 2007) The next section deals with these so-called agent-based models.

[7] LUCC = land-use/cover change.

2. Agent-based models

In contrast to cellular automata based models that focus on landscapes and transitions, agent-based models focus on human action. They thus emphasise the decision-making process of the agent (which can represent any level of organisation) and the social organisation and landscape in which these individuals are embedded. Since adequately representing agent behaviour and linking it to actual land areas is a very difficult task, well established agent-based models have become available only recently. (Verburg and Overmars, 2007). They employ some variant of bounded rationality, because perfect rationality is not very realistic given the complexity of land use systems. Boundedly rational agents "have goals that relate their actions to the environment. Rather than implementing an optimal solution that fully anticipates all future states of the system of which they are part, they make inductive, discrete, and evolving choices that move them toward achieving goals." (Parker et. al, 2003)

For an extensive explanation of agent-based modelling, see Gilbert (2007).

Evans and Kelley (2004) give an example of an agent-based, spatially explicit, modelling framework. Each of the landownership units of the landscape (parcels, composed of a set of regular sized cells) is associated with individual simulated agents (households). Both the cells and the households have characteristics. At each time point, households evaluate the land uses of the cells they own and, if they judge it necessary, make land conversion decisions. The general model consists of a set of discrete modules, including agent-decision-making dynamics, household demographics, land use change and biophysical processes and crop price. Within these modules, system processes are programmed.

Other examples of agent-based models include SIMPOP (Sanders et al., 1997), SIMPOP2 (Bretagnolle et al., 2006) and MameLuke (Huigen, 2004).

The choice between pixel-based and agent-based models is not an easy one and depends both on the objectives of the study and the available information and resources. Given the complexity of the land use system, the use of different model approaches, the results of which are afterwards compared, might be appropriate. Another possibility is to use different approaches sequentially, e.g. first use agent-based models to explore mechanisms that can later on be included in spatial simulation models. (Verburg and Overmars, 2007) In multi-agent system models of land-use/cover change (LUCC), both key components are integrated through specification of interdependencies and feedbacks between agents and their environment. This allows to simulate the complex interactions among agents and between agents and their environment in a manner that assumes no equilibrium conditions, to link observations at a range of spatial and temporal scales and to generate observable behaviour at multiple levels. (Parker et al., 2003)

Apart from these two large 'families' of recently developed models, some 'hybrid' models exist, which cannot be classified into a single model category. Probably the best known hybrid model is the CLUE model, described in the next section.

3. The CLUE modelling framework

Hybrid models are a new generation of models that combine a 'classic' estimation model with a simulation model (Irwin and Geoghegan, 2001). A recent example of such a hybrid, spatially explicit model is the CLUE (Conversion of Land Use and its Effects) model, developed at the Wageningen Agricultural University (the Netherlands) to model land use changes as a function of their driving factors. The first version was published in 1996 and the model is now one of the most widely applied modelling frameworks. The CLUE framework is an "integrated, spatially explicit, multi-scale, dynamic, economy-environment-society-land use model". (Briassoulis, 2000) It can be considered a cross-disciplinary model since it integrates environmental modelling and a geographic information system (Veldkamp and Fresco, 1996a). For an extensive description of the model, see Veldkamp and Fresco 1996a, 1996b, 1998; Verburg et al., 1997; de Koning et al., 1998; Verburg et al., 1999; Verburg and Overmars, 2007; www.cluemodel.nl).

In a first step, multiple regression analysis is used to analyse past and present land use patterns at various levels of spatial aggregation. Is this way, the most important bio-physical and socio-economic determinants of land use at each level of aggregation as well as the quantitative relationships between them and the area of various land use types are determined. The results of the analysis of the first step are used in the second step to explore possible future land use changes within a spatially explicit framework using scenarios of future socio-economic development.

The CLUE modelling framework is composed of four modules. The demand for various types of land use is taken up by the Demand Module. The calculations of the demand module are based on the national level demand for various commodities, which consists of domestic consumption and exports. Domestic consumption is assessed as a function of population size, composition (urban and rural) and consumption patterns, while exports are assessed exogenously and they are related to international prices and national subsidies. The necessary demographic input to the demand module is given by the Population Module. Consumption patterns may be related to macro-economic indicators like GNP, purchasing power and price levels. Different scenarios are formulated to account for difficult-to-predict changes in demand. The Yield Module assesses the yield of each of the main land use/cover types as a function of their surface area (in each cell of the study area), bio-physical conditions, technology level, management level and their general intrinsic cover value. The Allocation Module provides for the actual allocation of the demand for land by land use/cover type generated by the Demand Module to the cells of the study area in accordance with the ability of land in each cell to support the actual demand as assessed by the

Yield Module. A nested scale approach is applied for this allocation drawing on the idea that local land use change is the product of changes in both the drivers of land use at higher scales as well as of changes in local bio-physical and socio-economic conditions.[8] The regression equations estimated from the first step of the modelling procedure are used to calculate the land use changes at each spatial level. This allocation procedure attempts to integrate top-down with bottom-up demands and constraints to simulate the effects of future changes in the drivers of land use. (de Koning et al., 1998)

Recently, a modified version of the CLUE model, the CLUE-s model, was developed which makes possible high resolution representation of land use with homogeneous pixels (each pixel only contains one land use type). Improved computer capacity and data availability now allow to simulate high-resolution land use changes for large areas, e.g. the European Union. (Verburg and Overmars, 2007).

Until recently, there has always been a relatively strict subdivision between urban and rural models of land use change, with distinctly different modelling procedures: urban models primarily used neighbourhood functions such as cellular automata and infrastructure, rural models were generally based on land-quality assessments as the basis of simulation. The CLUE modelling framework offers the possibility to combine different procedures for land allocation within one modelling framework. (Verburg and Overmars, 2007) According to Briassoulis, the CLUE modelling framework is "a worthwhile attempt to address the land use change issues as it is sensitive to the requirements of integration along all dimensions with a special emphasis on the critical spatial dimension. It adopts a macro-, aggregate approach to the analysis of land use change and it is intended primarily to serve as a predictive tool in analyzing the land use impacts of future development scenarios at large scales–regional and national. It is relatively simple to comprehend and functional to use." However, the CLUE research group itself emphasises that to become a reliable policy support instrument, the modelling framework requires further elaboration (high spatial resolution data, linkages to farming systems analysis, land evaluation systems, and optimisation planning models). Furthermore, the explanatory capability of the CLUE modelling framework is limited because of its use of statistical procedures, which, as Briassoulis (2000) argues, should be complemented by thorough analysis using other, mostly qualitative techniques. A final and very important weakness of CLUE is the absence of a rigorous theoretical basis.

The main disadvantage of CLUE is the same as that of the cellular automata models: the unit of observation is not the individual decision-maker: "Because the underlying decision-making unit behaviour is imposed, it is not possible to model a behavioural response to a change in any variable included in the models" (Irwin and Geoghegan, 2001).

[8] More details on the multi-scale approach of the CLUE model can be found in Veldkamp et al. (2001a,b).

B. Endogenous Growth and Technical Change

1. Endogenous Growth and New Economic Geography

New theories of endogenous growth and the New Economic Geography literature share some important assumptions. Both rely extensively on increasing returns and imperfect competition which lie at the basis of their most important results, so it should not be surprising that both strands of theories have been successfully integrated. In this paragraph we review some of the implications of the symbiosis of New Growth Theory and New Economic Geography. The paragraph draws heavily upon chapter 7 in Baldwin et al. (2003).

Baldwin et al. (2003) describe a model which builds on Romer's model of technical change (see also chapter 6 in Barro and Sala–i–Martin, 2004). The driving force of economic growth in Romer's model is the continuous expansion of varieties due to sustained R&D effort. This growth model is embedded in a two region economic geography model. In both regions capital as well as labour is assumed to immobile across borders. The regional capital stock is owned by the regional labour force, so capital income is being spent locally. Capital is used as a fixed factor of production, where one unit of capital is used to produce one variety. Capital should thus be thought of as an 'idea' instead of a physical unit. Capital depreciation is modelled as a constant probability of the obsolescence of an idea. Labour is the only variable cost, production does not use any intermediate good. Research activity is modelled through an artificial research sector. The modelling of the research process is crucial to the eventual outcome. The cost of research is assumed to fall with the number of existing varieties/ideas. Research is thus assumed to follow a so-called learning curve, which is crucial to undercut the mechanism implied by the Dixit–Stiglitz setting, where expanding varieties imply falling profits due to increased competition. Different assumptions could be made on the stock of existing ideas which can be used to describe the learning curve. In the 'global spill-over' case, the relevant number of ideas consists of the whole stock of varieties existing in the world. In the 'local spill-over' case the relevant number of ideas only consists of the regional stock of varieties. This case is a way of modelling the importance of proximity and networking in the research process. The distinction matters for the strength of agglomeration forces, as can be expected.

In both cases, agglomeration dynamics are driven by forces that are able to influence the willingness to invest in new technologies (in the model captured by Tobin's q). In the global spill-over case, two forces influence the research sector's incentive to invent new ideas. The well-known demand linkage works to enhance research: an exogenous shock leading to a rise in a region's capital stock will boost capital income, which in turn raises expenditure, which raises profits and thus the incentive to invest. This positive effect is countered by the market crowding effect: an increased number of varieties in a region raises competition, which lowers the value of new investment. In the local spill-over case these two well–known effects are supplemented by a novel effect, working to encourage regional growth. Since the productivity of the regional research sector depends on the regional stock of inventions, an exogenous positive disturbance raises the attractiveness of research in one region, thus raising growth in that region. This effect has been named "localised spill-over effect".

As in all NEG models, the strength of these spatial effects depends on trade freeness, and thus on the level of transport costs. The local spill-overs version has been used to analyze the impact of different kinds of infrastructure investments (i.e. intraregional or interregional) on regional development. (See Martin and Ottaviano (1999) and Martin and Rogers (1995))

Agglomeration forces in this model do not work through migration of labour, or through the mobility of capital, but through different endogenously determined growth rates between regions. The model relates closely to the literature describing agglomeration through 'growth poles' and 'growth sinks'. (See e.g. Perroux, 1995).

2. Endogenous Technical Change and environmental modelling

There is a widespread agreement that the reaction of technology to policy is crucial in estimating the impact of different policies on issues like energy and the environment. Pizer and Popp (2007) take stock of recent empirical evidence of the endogeneity of technical change, and of the way in which the modelling profession has attempted to introduce these effects in applied models.

A first important issue concerns the private R&D process. It is well known that the social returns to R&D far outweigh the private return. Due to the public good nature of most knowledge embodied in an invention, the general public will benefit from research done by a private innovator. Due to this divergence between the private and the social rate of return, the private sector will in general not provide the socially optimal amount of research. For environmental policy modelling, this creates two challenges. First, the impact of policies to encourage more R&D should be modelled properly. Is the government able to encourage more research? Second, the true cost of funnelling resources to environmental R&D should be properly estimated. If there is at least partial displacement of other kinds of R&D, a dollar invested in environmental R&D should be valued by the proper opportunity cost, namely the high social rate of return that could be achieved through other R&D.

There exists mixed evidence of the impact of policy on R&D. Lanjouw and Mody (1996) and Brunnmeier and Cohen (2003) look at the relationship between pollution–abatement expenditures and environmental patents. Pollution control expenditures are taken as a proxy of the stringency of environmental regulation. Both find positive, albeit small effects. Popp (2002) finds positive effects of lagged energy prices and energy R&D activity.

Modellers have responded in various ways to the range of empirical evidence described above. A choice has to be made on the form of the model (whether R&D works to improve emissions intensity, abatement costs or sectoral productivity) and the parameterisation of effects (the social rate of return and displacement effects). Nordhaus (2002) for example links the rate of growth of carbon intensity to R&D input and expresses the cost of one unit of R&D input as 4 units of output reflecting the above displacement effect. Buonanno et al. (2003) links the level of carbon intensity to the total stock of accumulated R&D and relate the productivity of environmental R&D positively to R&D performed elsewhere. Goulder and Mathai (2000) let abatement costs depend on the stock of existing knowledge, whereas in the multi–sectoral model of Goulder and Schneider (1999) the stock of knowledge influences sectoral productivity. In the latter model, no sectoral spillovers exist given the lack of research on the existence of positive spillovers and crowding out between sectors.

Next to private R&D efforts, Pizer and Popp (2007) consider the effect of learning by doing mechanisms. These effects could be very important from a welfare point of view compared to R&D, since the former does not entail such a high opportunity cost. Gauging the relative importance of learning by doing and R&D in influencing is done by estimating a learning curve (cost in function of cumulative capacity) augmented by a term for the stock of R&D. The few studies in this field have found only modest impacts of learning by doing, compared to R&D. Moreover, studies on the learning curve have suffered from concerns about the direction of causality, and the possible endogeneity of regressors. Nevertheless, learning curves have been applied in models (see e.g. Goulder and Mathai, 2000).

The precise impact of government R&D is even less understood. The wedge between the private and the social rate of return has been documented for private R&D, but the return of government R&D is less well known, due to its usually fundamental and long term nature. This uncertainty about the precise impact of government research creates difficulties for policy oriented research. Given the divergence in private and social rate of returns one would expect government intervention, through R&D subsidies or tax cuts to be beneficial. Unfortunately one does not know whether existing policy corrects for the rate of return difference or not. In other words, in applied models, government research enters the baseline scenario of a policy model in a hidden way, making it difficult to judge upon the value of an incremental change in policy.

Another issue to be tackled is the gradual adaptation of a new technology. Although empirical evidence exists on the nature of the diffusion process, the gradual adoption of technologies is still modelled in an ad hoc way. Empirical evidence has shown, however, that the process of adoption varies according to the nature of the technology, and the incentives faced by firms. In the environmental field, end–of–pipe technologies are more likely to be adopted quickly under pressure of government regulation, while energy efficiency technologies are more likely to be adopted at the rate of the well documented S–curve. (See e.g. Popp, 2005 and Rose and Joskow, 1990) Ideally, models of technological change should then distinguish among different kinds of technologies, which is rarely done in practice.

C. Location decisions of households and firms

A case in point of a situation where an individual or household has to choose among a set of discrete alternatives, is housing consumption. Discrete choice models[9] are therefore the straightforward techniques of modelling household decisions regarding housing. The basic framework underlying these models is random utility theory. According to this theory, the decision-maker evaluates the attributes associated with a set of discrete alternatives and chooses the alternative which maximises utility, subject to his tastes and constraints.

Because of its computational simplicity, the multinomial logit model is the most commonly used discrete choice model in this context. However, this computational simplicity is paid for by the irrealistic Independence of Irrelevant Alternatives (IIA) assumption. This assumption states that the ratio of choice probabilities is independent of the presence or absence of any other alternative in a choice set (Hensher et al., 2005).

To model a more flexible pattern of substitution, the multinomial logit model has been generalised to a nested multinomial logit model (McFadden, 1978, 1981; Fischer and Nijkamp, 1985, Clark and Van Lierop, 1986). In a nested multinomial model, the utilities of alternatives in common groups may be correlated. This possibility is accounted for by introducing a scale parameter (associated with the 'inclusive value') into the variance of each of the unobserved components of utility. The variances within any nest are assumed to be equal but they may vary between nests.

The framework of the nested logit model was designed by McFadden in his seminal work of 1978. Quigley (1976) pioneered this technique in a housing market context with a study of short-term housing demand in Pittsburgh. Since the 1980s, a wide range of disaggregate models of housing choice have been developed. Only few of them, however, explicitly take into account the institutionalised and regulated nature of the housing markets in Western Europe.[10]

According to Koppelman and Wen (1998) the applications of the nested multinomial model can be divided into two main categories: the McFadden nested logit model, derived from random utility theory, and the Daly non-normalised nested logit model, based on probability relationships that are not consistent with utility maximisation. In the former, the non-normalised parameters are constrained to be the same across all nodes within the same level of a tree. In the latter this is not the case.

[9] For an overview of discrete choice modelling methods, see amongst others Ben-Akiva and Lerman (1985), Hensher et al. (2005), Hutchinson (1985), Long (1997), Pitfield (1984), McFadden (2001) and Train (2003).
[10] In the United States governmental control and interventions on housing markets is nearly non-existent, which makes an analysis based on the economic theory of competitive markets less problematic.

Although the nested logit model addresses the IIA assumption that underpins the multinomial model, it has a severe drawback: the tree structure is intuitively constructed and imposes a hierarchical choice that is not always a good reflection of the real choice process. Moreover, the IIA assumption is only partially relaxed since the variance is partitioned into nests (similar alternatives are nested). In order to obtain a completely unrestricted estimation procedure, one would have to implement the heteroscedastic extreme value discrete choice model (Louviere et al., 2000), a model that can reveal tree structures that may not always be intuitively obvious.

The discrete choice framework has also been applied to model firm location decisions. Carlton (1983) was the first to apply the conditional logit model to industrial location decisions. However, the IIA assumption hindered further progress in this line of research. More recently, Poisson models have been applied in empirical studies of industrial location, but these studies are not based on the random utility maximisation framework. In their paper of 2004, Guimarães et al. show how the potential IIA violation can be effectively controlled for in complex choice scenarios, by "taking advantage of an equivalence relation between the likelihood functions of the conditional logit model and the Poisson regression" (Guimarães et al., 2004). Moreover, such approach has a sound theoretical foundation, which is missing in the Poisson models.

D. The labour market

1. Regional labour markets

Job search theory is currently the main theoretical and empirical framework to analyze labour markets, building on the work of Stigler (1961, 1962). Search theory allows for market imperfections (lack of information, moving costs), contrasting with the standard urban economics model which assumes that markets are perfect (Anas, 1982; Hamilton, 1982). The most general search model is the job matching model where search behaviour of job seekers and employers are both explicitly modelled and commuting costs, wages, number of unemployed and number of vacancies are endogenously determined (Rouwendal, 1998).

The imperfectness of the labour market is related to its spatial dimension. A searcher may be unaware of employment opportunities because he does not visit the place where information about them is available. Information on job conditions and candidates aptitudes is not freely and immediately available to all market participants as would be the case in a perfect market. Due to these information-based market imperfections, time consuming search is necessary to match searchers with vacant positions.

A spatial job search model adds an additional dimension to the non-spatial job search literature. The spatial dimension is unimportant if workers are willing to move to a residential location close to any offered job and are able to realise such moves at a low cost. It seems unlikely that these conditions are fulfilled. In general, residential mobility is very costly and commuting is also costly. The duration of unemployment is determined in part by the acceptance behaviour of the unemployed concerning job offers. This acceptance behaviour is related to the spatial dimension of the labour market.

In a perfect market there can only be one price for a commodity. In the case of the labour market this means that identical jobs will be offered at the same wage. Therefore the question arises why employers offer different wages for identical jobs. If similar jobs are offered at different locations and job searchers are spread over the labour market, the utilities of offered jobs depend on the locations of the job and of the searcher to which it is offered, even if all employers offer the same wages. Only in the special case when employers completely compensate their worker's generalised commuting costs will there be no variation in net wages on a spatial labour market.

Van Ommeren and Rietveld (2002) describe the functioning of a multi-regional equilibrium search model for the labour market. They assume that regional labour supply is fixed, and that the number of vacancies, the number of unemployed and wage levels are endogenously determined given productivity levels. Due to search frictions, in each region, unemployment and vacancies exist at the same time.

Rouwendal and Rietveld (1994) noticed the potential relevance of search theory for analyzing commuting distance distributions. They estimated reduced form equations for commutes with wages and a number of worker characteristics as explanatory variables. Even though their results do not provide direct information on the values of the parameters of the individual searcher's utility functions, they are suggestive of some of the determinants.

Rouwendal (1999) developed a much more elaborate model that allows for estimation of the structural parameters of the search model. The model is intended to explain the observed combinations of wages and commuting distances in cross section data.

In urban economics, attention for models based on optimal spatial job search has been limited thus far; papers on this topic include Rouwendal (1998), Wasmer and Zenou (2002, 2006). Rouwendal and van Vlist (2005) develops a model for a spatial labour market in which employment is concentrated at discrete points in space. The employment centres are surrounded by residential areas and workers can be employed in their city of residence as well as in another city. Unemployment is larger where there is less accessibility to jobs. Employed workers generate value added. Two main frictions can be identified within this model: First, travel costs cause some of the value added to leak away, on the other hand, because of vacant positions there is a gap between actual and potential total value added. The model allows for welfare economic analysis of improvements in traffic infrastructure.

The benefit of more commuting is a flexible labour supply and more efficient labour markets with lower unemployment. The costs are mainly the negative externalities created through transportation activities. Therefore, commuting has costs and benefits that are traded off in equilibrium. Pilegaard (2003) formulates a theoretical framework that combines imperfect labour markets with a transport externality (congestion) in a spatial framework. Structural unemployment is included in the analysis.

2. Non–competitive wage formation in NEG models

The earliest theoretical literature in the "New Economic Geography" has not paid a lot of attention to the functioning of the labour market. In the major theoretical models presented in the book of Baldwin et al. (2003) for example, the labour market is routinely taken to be of the competitive kind. Wages are thus assumed to be able to fully react to changes in labour supply and demand.

Recently however, European theorists in the NEG school have been paying attention to the role of the labour market assumptions in driving the main results of the canonical NEG models. A notable contribution has been made by Puga (1999). In the context of European integration, he asks whether the so–called Tomahawk, namely the inevitable clustering of economic activity at low trade costs can somehow be avoided. This is of course of prime interest to European policy makers. European integration has caused a rapid and sustained falling of trade costs in Europe, which has led to increased pressure on peripheral regions due to strengthening agglomeration forces. Given current labour immobility in Europe, both across nations as well as across regions, it is therefore interesting to ask out of social and political concern whether this process of agglomeration is inevitable or can be reversed by further integration.

In order to lay the theoretical foundations, Puga (1999) constructs a model integrating and extending some of the canonical NEG models. His model displays the well known demand and cost linkages of Krugman (1991) as well as the vertical linkages of Krugman and Venables (1995). He adds to this the finitely elastic supply of 'agricultural' labour to the 'industrial' sector. This last feature will induce a counterbalancing affect to agglomeration. The expansion of 'industry' in a region will (if labour is not mobile across regional borders!) inevitably cause wages to rise compared to the losing regions thus discouraging clustering. At lower levels of trade costs, this effect will come to dominate the agglomeration forces (which fall in strength as trade costs fall, while the other effect does not), so dispersion sets in again as integration continues to deepen. Note that wages play the same role as the housing and land price do in the model of Helpman (1998) (cf. supra). There is thus at least a theoretical possibility that European integration will not cause peripheral regions to lag behind indefinitely. However, although he does not work this idea out formally, Puga goes on by suggesting that wage inflexibility caused by supra–regional wage setting will null the above equilibrating mechanism, and thus lock peripheral regions in their vulnerable position. Of course, the same line of reasoning may explain the current situation of Eastern Germany, the Italian Mezzogiorno, and possibly Wallonia. It is assumed that in these countries an insider dominated union sets wages to appropriate the rents of agglomeration, while at the same time these wages based on conditions in the core are imposed on the periphery to maintain these rents.

Formal theoretical models integrating non–competitive wage setting are scarce. De Bruyne (2005) constructs a theoretical model where wages are bargained either at different levels (nationally, regionally or at the firm level). She shows how peripheral regions would lose from collective, supra–regional bargaining, whereas core regions win from such a regime.

E. Ecological–Economic modelling

An extensive literature has analyzed optimal taxation and tax reform in the presence of externalities in a second-best framework. Most papers assume that environmental quality enters the utility function in a separable way and therefore ignore the feedback effect of environmental quality on the behaviour of the economic agents. The implications of taking into account the feedback effects are considered in Mayeres and Proost (1997, 2001), Schwartz and Repetto (2000) and Williams (2002, 2003). Mayeres and Proost (1997) derive optimal tax rules in the presence of an externality with a feedback effect for an economy with distortionary taxes. They show that the optimal tax on an externality generating good equals the sum of a revenue-raising component and the net social Pigouvian tax. The net social Pigouvian tax takes into account the damage imposed by the externality on consumers and producers. It will be smaller if a higher level of the externality leads to more consumption of the taxed commodities. Williams (2002) demonstrates that the welfare effect of an externality tax consists not only of a tax interaction and revenue recycling effect, two well-known effects, but also of a benefit side tax interaction effect. Williams considers four possible routes through which air pollution may affect the pre-existing distortions. First, if improved air quality leads to less medical spending, this creates an income effect that reduces labour supply, thereby worsening existing distortions. Secondly, if better air quality reduces time lost to illness, the benefit side tax interaction effect is ambiguous. Thirdly, when cleaner air leads to higher labour productivity, labour supply is boosted and the existing distortions are mitigated. Finally, if a cleaner environment improves the productivity of a fixed factor, the benefits of the externality tax are reduced.

Though many CGE models aiming at evaluating environmental policies consider only the costs of environmental policy measures, in the standard GEM-E3 model and some other CGE models, the benefits of environmental policies are modelled, through an index of environmental quality that depends on emissions and that provides an ex-post contribution to the consumers' welfare[11]. These models consider a one-way link between the evolution of the economic variables and the level of environmental quality.

[11] See also Glomsrod et al. (1992), Ballard and Medema (1993), Boyd et al. (1995), and Brendemoen and Vennemo (1996).

However, the level of environmental quality or the level of other externalities (congestion, accidents,…) may also affect economic performance. A number of CGE models incorporate some of these feedback effects. Examples of such CGE models[12] are Nordhaus (1994), Vennemo (1997), Mayeres (1999), Bergman and Hill (2000), Conrad and Heng (2002), Chung-Li (2002) and Mayeres and Van Regemorter (2008). Nordhaus (1994) models the impact on production of the accumulation of CO_2 emissions which increases the temperature of the earth. Vennemo (1997) evaluates the external effects of economic activity in terms of their costs on the economy. The paper produces damage estimates for acidification of lakes and of forests, for health and annoyance from emissions of NO_x, SO_2, CO and particulates, for corrosion, noise, traffic accidents, congestion and road depreciation. Vennemo finds that the feedback on environmental quality is much more significant for consumer welfare than the feedback in the form of increased depreciation and a decline in productivity. Bergman and Hill (2000) consider the productivity effects of environmental stock and flow pollution by including the effects from pollution accumulation on production. To model the feedback effects, the resource endowments are included in the model and the externality is linked to these endowments. The feedback of traffic and congestion on economic variables is considered by Mayeres (1999) and Conrad and Heng (2002). Mayeres and Van Regemorter (2008) explore how the health related benefits of environmental policies can be modelled in a more realistic way in GEM-E3 and what the implications for the welfare evaluation of environmental policies are. A similar exercise for Thailand is presented by Chung-Li (2002), who explores the economy-wide repercussions of improved air quality through its effect on labour supply and medical expenditure. The extension of the GEM-E3 model in Mayeres and Van Regmorter (2003) concentrates on the health impacts of air pollution, as they are the largest gain from an improvement in air quality. The effects of air pollution on vegetation, materials and visibility are still taken into account ex-post. Within the health impacts, a distinction is made between the impact on medical spending by the consumers and the public sector, the impact on the available time of the consumers and the impact on labour productivity. Thus the analysis considers three of the four sources of the benefit side tax interaction effect presented by Williams (2002). A health production function is used that relates a continuous health variable to pollution and the consumption of medical care. This approach is most appropriate for modelling the morbidity effects of air pollution. A realistic treatment of the mortality impacts would require modelling health states rather than a continuous health variable (see, e.g., Freeman (2003)). Mayeres and Van Regemorter (2008) focuses on the morbidity effects, while the mortality impacts continue to be modelled in the traditional way, i.e. ex-post, except for the medical costs related to them.

A more realistic modelling of the non-health related effects of air pollution in GEM-E3 is presented in Bergman and Hill (2000).

[12] For an overview, see Conrad (2002).

F. Stochastic elements in general equilibrium models

The class of general equilibrium models that incorporate stochastic elements, is called Dynamic Stochastic General Equilibrium (DSGE) models. These models differ from the traditional general equilibrium models in that they incorporate one or several model elements, which are estimated econometrically using the time-series data and include a stochastic element in the form of the error term of the estimated regression equation. Regression equations used as parts of the DSGE models can be both linear and nonlinear. They can also include autoregressive terms.

In the case of extremely good data availability, all the coefficients of the DSGE model can be estimated econometrically. In that case the DSGE models are linearised by applying a logarithm transformation and afterwards estimated on the time-series data using either maximum likelihood method or the generalised method of moments. Such estimated DSGE models usually have a very simple structure, which is closer to the structure of the traditional macro-economic models than to the structure of the CGE models.

DSGE models have become a standard tool in various fields of Economics, most notably in Macroeconomics and International Economics. DSGE models are attractive because they explicitly specify the objectives and constraints faced by households and firms, and then determine the prices and allocations that result from their market interaction in an uncertain environment.

The main elements of the DSGE models, which are estimated econometrically and incorporate uncertainty about the future development of the economy, include:

- Technological progress: in order to account for the technological development in the DSGE models, they include an exponential first order autoregressive process which explains development in time of the total factor productivity coefficient of the production functions. The level of total factor productivity at time *t* is assumed to be fully explained by the constant term, the last period total factor productivity and the stochastic error term. It is possible to extend this regression equation and incorporate other factors explaining the development of the total factor productivity of the country such as the last period R&D investments, share of the highly educated persons in the country, governmental spending on education etc.

- Development of the knowledge capital: the development of knowledge capital in the economy is introduced in the same way as technological progress via a regression equation which explains the present level of the knowledge capital by its last period level and by the public and private investment in education made during the previous time period plus an error term.

- Flow of Foreign Direct Investments (FDI): the flow of FDI to the economy is captured by the regression equation, which explains the level of FDI by the capacity of the market, availability of the qualified labour in the country, the stock of the national natural resources plus the error term.

Another way of introducing uncertainty into the DSGE models is the introduction of structural shocks associated with the different model variables. The structural shocks can be associated with supply and demand, labour productivity and labour supply. The demand shocks can include preference shocks, governmental consumption shocks and investment consumption shocks. The shocks in the DSGE models are the stochastic processes/variables estimated on the time series data. The introduction of these shocks allow for explaining the economic fluctuations which are not captured by the structure of the model.

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Annex 4 to the final report of the **LIMOBEL** project (Long run impacts of policy packages on mobility in Belgium), financed by the Belgian FPS Science Policy. (Contract SD/TM/01B)

Federal Planning Bureau **NOTE**

LIMOBEL Annex 4 – List of Variables and Equations of the CGE Model

December 2010

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Table of Contents

1. CGE model – list of variables

VARIABLE	DESCRIPTION
Production - Prices	
$PPnonelec_{s,r,g}$	Price of non – electricity energy inputs
$PPelec_{s,r}$	Price of electricity inputs
$PPint_{s,r,g}$	Price of material inputs
$PPtpint_{s,r,g}$	Price of transport material inputs
$PPtpcap_{s,r}$	Price of transport capital inputs
$PPlab_{s,r}$	Price of labour services
$PPcap_{s,r}$	Price of capital services
$PPnonelecT_{s,r}$	Price index of non electricity energy goods nest
$PPenergy_{s,r}$	Price index of energy goods nest
$PPintT_{s,r}$	Price index of intermediate goods nest
$PPcapen_{s,r}$	Price index of KE nest
$PPlabint_{s,r}$	Price index of LM nest
$PPtpintT_{s,r}$	Price index of transport material inputs nest
$PPtpinp_{s,r}$	Price index of transport inputs nest
$PPklem_{s,r}$	Price index of KLEM nest
$PPtklem_{s,r}$	Price index of upper nest
$PPtot_{s,r}$	Marginal production costs
Production - Quantities	
$XPnonelec_{s,r,g}$	Non – electricity energy inputs
$XPelec_{s,r}$	Electricity inputs
$XPint_{s,r,g}$	Material inputs
$XPtpint_{s,r,g}$	Transport material inputs
$XPtpcap_{s,r}$	Transport capital
$XPlab_{s,r}$	Labour services
$XPcap_{s,r}$	Capital services
$XPnonelecT_{s,r}$	Total non – electricity energy input
$XPenergy_{s,r}$	Total energy input
$XPcapen_{s,r}$	Total KE input
$XPintT_{s,r}$	Total material input
$XPlabint_{s,r}$	Total LM input
$XPklem_{s,r}$	Total KELM input
$XPtpintT_{s,r}$	Total transport materials input
$XPtpinp_{s,r}$	Total transport inputs
$XPtklem_{s,r}$	Total output net of taxes on production
$XPXVPtot_{s,r}$	Total output, taxes included
Freight and Trade - Prices	
$PMT6HDV_{r,rr,g,l,pr}$	Price of monetary inputs for one vkm by Heavy Duty Vehicle
$PMT6LDV_{r,rr,g,l,pr}$	Price of monetary inputs for one vkm by Light Duty Vehicle
$PMT6Rail_{r,rr,g,l,pr}$	Price of monetary inputs for one vkm by Rail
$PMT6Iww_{r,rr,g,l,pr}$	Price of monetary inputs for one vkm by Internal Waterways
$PTT6HDV_{r,rr,g}$	Price of time inputs for one vkm by Heavy Duty Vehicle
$PTT6LDV_{r,rr,g}$	Price of time inputs for one vkm by Light Duty Vehicle

$PTT6Iww_{r,rr,g}$	Price of time inputs for one vkm by Internal Waterways
$TT6HDV_{r,rr,g,l,pr}$	Time requirement for one vkm by Heavy Duty Vehicle
$TT6LDV_{r,rr,g,l,pr}$	Time requirement for one vkm by Light Duty Vehicle
$PT6_{m,r,rr,g,l,pr}$	Generalized cost of freight by mode by period
$PT5Road_{m,r,rr,g,l}$	Generalized cost of road freight by location
$PT5Rail_{r,rr,g,l}$	Generalized cost of rail freight by location
$PT5Iww_{r,rr,g,l}$	Generalized cost of IWW freight by location
$PT4Road_{m,r,rr,g}$	Generalized cost of road freight by mode
$PT4Rail_{r,rr,g}$	Generalized cost of rail freight by mode
$PT4Iww_{r,rr,g}$	Generalized cost of Iww freight by mode
$PT3Road_{r,rr,g}$	Generalized cost of road freight
$PT3RailIww_{r,rr,g}$	Generalized cost of RailIww freight
$PT2Transport_{r,rr,g}$	Generalized cost of freight transport
$PT2Services_{r,rr,g}$	Price of freight related services
$PT1Freight_{r,rr,g}$	Price of freight
$PT1Comm_{r,rr,g}$	Price of transported commodities
$PT0Good_{r,rr,g}$	Price of transported goods, freight charges included
$PA2_{r,rr,g}$	Price of domestically traded goods, interregional
$PA1Dom_{r,g}$	Price of domestically traded goods
$PA1Eu_{r,g}$	Price of imports from European Union
$PA1Row_{r,g}$	Price of imports from Rest of the World
$PA0_{r,g}$	Price of domestic demand
$XT5Road_{m,r,rr,g,l}$	Road freight transport by location
$XT5Rail_{r,rr,g,l}$	Rail freight transport by location
$XT5Iww_{r,rr,g,l}$	IWW freight transport by location
$XT4Road_{m,r,rr,g}$	Road freight transport by mode
$XT4Rail_{r,rr,g}$	Freight transport by Rail
$XT4Iww_{r,rr,g}$	Freight transport by IWW
$XT3Road_{r,rr,g}$	Freight transport by Road
$XT3RailIww_{r,rr,g}$	Freight transport by Rail and IWW
$XT2Transport_{r,rr,g}$	Freight transport
$XT2Services_{r,rr,g}$	Freight related services
$XT1Freight_{r,rr,g}$	Total freight handling inputs
$XT1Comm_{r,rr,g}$	Traded commodities
$XT0Good_{r,rr,g}$	Trade goods, freight included
$XA2_{r,rr,g}$	Interregional Trade
$XA1Dom_{r,g}$	Domestic Trade
$XA1Eu_{r,g}$	Imports from the European Union
$XA1Row_{r,g}$	Imports from Rest of the World
$XA0_{r,g}$	Domestic demand
Households - prices	
$PC_{c,r}$	Price of consumption goods
$PT_{c,r}$	Total price of durable goods
$PCleis_{r}$	Price of Leisure / Value of Time
$PCndg_{r}$	Composite price of non durable goods
$PCdg_{r}$	Composite price of energy and durable goods
$PCleisTP_{r}$	Composite price of leisure transport
$PCcomm_{r}$	Composite price of commodities

$PTOT_r$	Price of utility
Households - quantities	
$QCexc_{c,r}$	Excess consumption
$QCenerC_{c,r}$	Consumption of energy linked to durable goods
$QCexcTOT_{c,r}$	Total excess consumption of energy, linked consumption included
$QC_{c,r}$	Total consumption
$QCleis_r$	Leisure time
$QCndg_r$	Total non durable good consumption
$QCdg_r$	Total consumption of energy and durable goods
$QCleisTP_r$	Total consumption of leisure transport
$QCcomm_r$	Total consumption of commodities
$QTOT_r$	Indirect utility
Households - Income	
$Yext_r$	Extended Income
$Ydisp_r$	Money Income
PW_r	Wage Rate
$CC_{TOT\,r}$	Unit monetary commuting costs
$CT_{TOT\,r}$	Unit time costs of commuting
SC_r	Total monetary costs of schooling trips
ST_r	Total time costs of schooling trips
LC_r	Total monetary costs of leisure trips
LT_r	Total time costs of leisure trips
$LABOUR_r$	Labour supply
$TOTCAPY$	Total capital income
LST_r	Lump sum tax
TRF_r	Government transfers
$SAVH_r$	Household Savings
Households transport - prices	
$PHT7_{CAR_{r,rr,mot,pr,socc}}$	Monetary price of car inputs for car transport
$PHT7_{DIES_{r,rr,mot,pr,socc}}$	Monetary price of diesel fuel inputs for car transport
$PHT7_{GAS_{r,rr,mot,pr,socc}}$	Monetary price of gasoline fuel inputs for car transport
$PMHT4_{MOTO_{r,rr,mot,pr}}$	Monetary price of motor transport
$PMHT4_{RAIL_{r,rr,mot,pr}}$	Monetary price of rail transport
$PMHT4_{FOBI_{r,rr,mot,pr}}$	Monetary price of foot and bike transport
$PMHT4_{BTM_{r,rr,mot,pr}}$	Monetary price of Bus, Tram and Metro transport
$THT4_{BTM_{r,rr,mot,pr}}$	Unit time requirement of Bus, Tram and Metro transport
$THT5_{CAR_{r,rr,mot,pr,socc}}$	Unit time requirement of car transport
$THT4_{MOTO_{r,rr,mot,pr}}$	Unit time requirement of motor transport
$PHT4_{RAIL_{r,rr,mot,pr}}$	Generalized price of rail transport
$PHT4_{FOBI_{r,rr,mot,pr}}$	Generalized price of fobi transport
$PHT4_{BTM_{r,rr,mot,pr}}$	Generalized price of BTM transport
$PHT6_{CAR_{r,rr,mot,pr,socc}}$	Total monetary price of car transport
$PHT5_{CAR_{r,rr,mot,pr,socc}}$	Total generalized price of car transport
$PHT4_{CAR_{r,rr,mot,pr}}$	Total generalized price of car transport, by period
$PHT3_{PRIV_{r,rr,mot,pr}}$	Total generalized price of private transport
$PHT3_{RAIL_{r,rr,mot,pr}}$	Generalized price of rail transport
$PHT3_{FOBI_{r,rr,mot,pr}}$	Generalized price of BTM transport

$PHT3_{BTM_{r,rr,mot,pr}}$	Generalized price of FOBI transport
$PHT2_{FAST_{r,rr,mot,pr}}$	Generalized price of fast transport
$PHT2_{SLOW_{r,rr,mot,pr}}$	Generalized price of slow transport
$PHT1_{r,rr,mot,pr}$	Generalized price of transport, by period
$PHT0_{r,rr,mot}$	Generalized price of transport, by motive
Household transport: quantities	
$XHT4_{MOTO_{r,rr,mot,pr}}$	Household transport, motor
$XHT4_{RAIL_{r,rr,mot,pr}}$	Household transport, rail
$XHT4_{FOBI_{r,rr,mot,pr}}$	Household transport, FOBI
$XHT4_{BTM_{r,rr,mot,pr}}$	Household transport, BTM
$XHT6_{CAR_{r,rr,mot,pr,socc}}$	Household transport, car
$XHT5_{CAR_{r,rr,mot,pr,socc}}$	Household transport, car
$XHT4_{CAR_{r,rr,mot,pr}}$	Household transport, car
$XHT3_{PRIV_{r,rr,mot,pr}}$	Household transport, private modes
$XHT3_{RAIL_{r,rr,mot,pr}}$	Household transport, rail
$XHT3_{FOBI_{r,rr,mot,pr}}$	Household transport, FOBI
$XHT3_{BTM_{r,rr,mot,pr}}$	Household transport, BTM
$XHT2_{FAST_{r,rr,mot,pr}}$	Household transport, fast modes
$XHT2_{SLOW_{r,rr,mot,pr}}$	Household transport, slow modes
$XHT1_{r,rr,mot,pr}$	Household transport, by period
$XHT0_{r,rr,mot}$	Household transport, by motive
Congestion	
$VKM_{SOLO_{r,rr,mot,pr}}$	Vehicle kilometres driven by car, solo
$VKM_{POOL_{r,rr,mot,pr}}$	Vehicle kilometres driven by car, pool
$VKM_{BTM_{r,rr,mot,pr}}$	Vehicle kilometres driven by BTM
$VKM_{MOTO_{r,rr,mot,pr}}$	Vehicle kilometres driven by motor
$VKMTransit_{r,rr,pr}$	Vehicle kilometres driven by transit freight
$VKM\quad_{m,r,rr,g,l,pr}$	Vehicle kilometres driven by freight
$PCU_{SOLO_{r,rr,mot,pr}}$	Passenger car equivalents, car-solo
$PCU_{POOL_{r,rr,mot,pr}}$	Passenger car equivalents, car-pool
$PCU_{BTM_{r,rr,mot,pr}}$	Passenger car equivalents, btm
$PCU_{MOTO_{r,rr,mot,pr}}$	Passenger car equivalents, moto
$PCUTransit_{r,rr,pr}$	Passenger car equivalents, transit freight
$PCU\quad_{m,r,rr,g,l,pr}$	Passenger car equivalents, freight
$ROADFLOW_{REG_{r,pr}}$	Road flow by region
$ROADFLOW_{r,rr,pr}$	Road flow by zone pair
$SPEED_{r,rr,pr}$	Speed, by zone pair
$SPEED_{REG_{r,pr}}$	Speed, by region
Labour Market	
$COMM_{r,rr}$	Commuters, by region
$TOTLAB_{r}$	Total labour demand
Governments	
$TAXREV_{prod_{gv,t}}$	Tax revenue from taxes on firms
$TAXREV_{hh_{gv,t}}$	Tax Revenue from taxes on households
$TAXREV_{inv_{gv,t}}$	Tax Revenue from taxes on investment
$TAXREV_{gov_{gv,t}}$	Tax Revenue from taxes on government consumption

$TAXREV_{hh_{gv,t}}$	Tax Revenue from taxes on households
$TAXREV_{TYPE_{gv,t}}$	Tax Revenue by type and government
$TAXREV_{TOT_{gv}}$	Total tax revenue by government
$GTRF_{gv}$	Transfers paid to households
$GOVBUDG_{gv}$	Government consumption budget
$GOVTRANSF_{gv,gvv}$	Total intergovernmental transfers
$BASICGEW_{gv}$	Basic grant received by Regional government
$NEGATIVE1_{gv}$	Negative term
$NEGATIVE2_{gv}$	Negative term associated with audiovisual taxes
$SOLIDARITY_{gv}$	Solidarity grant received by Regional governments
$TAXLOCGEW_{r}$	Localization factor of PIT, by region
$GRANTPIT_{gv}$	Grant to Community governments from Personal Income taxes
$GRANTVAT_{gv}$	Grant to Community governments from VAT
$LAMBERMONT_{gv}$	Grant to Community governments from Lambermont means
$TAXLOCGEM_{gv}$	Localization factor of PIT, by Community
$SAVG_{gv}$	Government savings
Saving and Investment	
$SAVDOM$	Domestic savings
INV	Investment
$NETINFLOW$	Net Inflow of capital
$XI1_{r,g}$	Investment demand
$PINV$	Price of Investment goods
ROR	Rate of Return (national)
ROR_{r}^{REG}	Rate of Return (regional)
Other	
$GDPREAL$	Regional GDP (rate of change)
CPI	Consumer price index
$GDPDEF$	Deflator of GDP

PARAMETER	DESCRIPTION
Production	
$\tau p_{nonelec\ g,t}$	tax rate on non electrical inputs
$\tau p_{elec_{t}}$	tax rate on electrical inputs
$\tau p_{int_{g,t}}$	tax rate on material inputs
τp_{t}^{K}	tax rate on capital services
$\tau p_{tpint_{g,t}}$	tax rate on transport related inputs
$\tau p_{tpcap_{t}}$	tax rate on transport capital
$\tau p_{prod_{s,r,t}}$	tax rate in production
$sp_{prod_{s,r,t}}$	subsidy rate in production
$\delta_{s,r}$	depreciation rate
$\alpha p_{g,s,r}^{6aa}$	share parameter non electrical inputs
$\alpha p_{s,r}^{5aa}$	share parameter electricity input
$\alpha p_{g,s,r}^{5abb}$	share parameter intermediate inputs
$\alpha p_{s,r}^{4ba}$	share parameter transport related inputs
$\alpha p_{s,r}^{3ba}$	share parameter transport capital inputs
$\alpha p_{s,r}^{4a}$	share parameter capital services

$\alpha p_{s,r}^{4b}$	share parameter labour services
$\alpha p_{s,r}^{3a}$	share parameter capital and energy
$\alpha p_{s,r}^{3b}$	share parameter labour and materials
$\alpha p_{s,r}^{2}$	share parameter KLEM inputs
$\sigma p_{s,r}^{4a}$	elasticity of substitution energy nest
$\sigma p_{s,r}^{3a}$	elasticity of substitution KE nest
$\sigma p_{s,r}^{3b}$	elasticity of substitution LM nest
$\sigma p_{s,r}^{2}$	elasticity of substitution KLEM nest
$\sigma p_{s,r}^{1}$	elasticity of substitution TFKLEM nest
$\varphi p_{s,r}^{4a}$	scaling parameter energy nest
$\varphi p_{s,r}^{3a}$	scaling parameter KE nest
$\varphi p_{s,r}^{3b}$	scaling parameter LM nest
$\varphi p_{s,r}^{2}$	scaling parameter KLEM nest
$\varphi p_{s,r}^{1}$	scaling parameter TFKLEM nest
Freight and trade	
$map_{g,s,r}$	mapping of goods on sectors
$\alpha Rail_{r}$	share by region of total rail freight demand
αIww_{r}	share by region of total iww freight demand
$\alpha Road_{r}$	share by region of total road freight demand
p_{g}^{abr}	price abroad
σ_{g}^{abr}	elasticity of substitution export demand
τm_{g}	import duties
$btt6_{m,r,rr,g,l,pr}$	unit time requirement for road transport, by mode
$bmt6_{m,r,rr,g,l,pr}$	unit monetary cost requirement for road transport, by mode
$\alpha t_{m,r,rr,g,l,pr}^{6}$	share parameter peak/off-peak travel
$\alpha t_{m,r,rr,g,l}^{5Road}$	share parameter location (road transport)
$\alpha t_{r,rr,g,l}^{5Rail}$	share parameter location (rail transport)
$\alpha t_{r,rr,g,l}^{5Iww}$	share parameter location (iww transport)
$\alpha t_{m,r,rr,g}^{4Road}$	share parameter mode (road transport)
$\alpha t_{r,rr,g}^{4Railiww}$	share parameter rail (rail iww transport)
$\alpha t_{r,rr,g}^{3Transport}$	share parameter road (all modes)
$\alpha t_{r,rr,g}^{2Freight}$	share parameter Transport (total freight handling)
$\alpha t_{r,rr,g}^{1good}$	share parameter Freight (total good)
$\sigma t_{m,r,rr,g,l}^{5Road}$	elasticity of substitution time period nest (road transport)
$\sigma t_{m,r,rr,g}^{4Road}$	elasticity of substitution location nest (road transport)
$\sigma t_{r,rr,g}^{4Rail}$	elasticity of substitution location nest (rail transport)
$\sigma t_{r,rr,g}^{4Iww}$	elasticity of substitution location nest (iww transport)
$\sigma t_{r,rr,g}^{3Road}$	elasticity of substitution mode nest (road transport)
$\sigma t_{r,rr,g}^{3Railiww}$	elasticity of substitution mode nest (railiww transport)
$\sigma t_{r,rr,g}^{2Transport}$	elasticity of substitution total transport nest
$\sigma t_{r,rr,g}^{1Freight}$	elasticity of substitution freight handling nest
$\varphi t_{m,r,rr,g,l}^{5Road}$	scaling parameter time period nest (road transport)
$\varphi t_{m,r,rr,g}^{4Road}$	scaling parameter location nest (road transport)
$\varphi t_{r,rr,g}^{4Rail}$	scaling parameter location nest (rail transport)
$\varphi t_{r,rr,g}^{4Iww}$	scaling parameter location nest (iww transport)
$\varphi t_{r,rr,g}^{3Road}$	scaling parameter mode nest (road transport)
$\varphi t_{r,rr,g}^{3Railiww}$	scaling parameter mode nest (railiww transport)

$\varphi t_{r,rr,g}^{2Transport}$	scaling parameter total transport nest
$\varphi t_{r,rr,g}^{1Freight}$	scaling parameter freight handling nest
$\alpha a_{r,rr,g}^{2}$	share parameter interregional trade flows
$\alpha a_{r,g}^{1dom}$	share parameter domestic trade
$\alpha a_{r,g}^{1eu}$	share parameter EU imports
$\alpha a_{r,g}^{1row}$	share parameter ROW imports
$\alpha a_{r,g}^{1}$	share parameter EU imports
$\alpha a_{r,g}^{1row}$	share parameter ROW imports
$\sigma a_{r,g}^{1}$	elasticity of substitution domestic trade nest
$\sigma a_{r,g}^{0}$	elasticity of substitution total trade nest
$\varphi a_{r,g}^{1}$	elasticity of substitution domestic trade nest
$\varphi a_{r,g}^{0}$	elasticity of substitution total trade nest
Households	
$mapH_{g,c,r}$	mapping of SUT goods and consumption goods
$\tau c_{c,t}^{ndg}$	tax rate on non durable goods consumption
$\tau c_{c,t}^{dg}$	tax rate on durable goods consumption
$\tau c_{c,t}^{ener}$	tax rate on energy goods consumption
$a_{dg,ener}$	unit energy requirement of durable goods
$\alpha c_{c2,c,r}^{2}$	share parameter of individual consumption goods
$\mu_{c,r}^{ener}$	minimum consumption energy goods
$\mu_{c,r}^{ndg}$	minimum consumption non durable goods
$\mu_{c,r}^{dg}$	minimum consumption durable goods
$\alpha c_{c2,r}^{1}$	share parameter of consumption categories
$\alpha c_{r}^{0LeisTP}$	share parameter of leisure transport categories
αc_{r}^{0comm}	share parameter of other consumer goods
αc_{r}^{0Leis}	share parameter of leisure
$\sigma c_{c2,r}^{2}$	elasticity of substitution lower consumption goods nest
σc_{r}^{1}	elasticity of substitution upper consumption goods nest
σc_{r}^{0}	elasticity of substitution top nest
$\varphi c_{c2,r}^{2}$	share parameter lower consumption goods nest
φc_{r}^{1}	share parameter upper consumption goods nest
φc_{r}^{0}	share parameter top nest
$\bar{T}$	Time endowment
ω_{r}^{K}	Share in capital ownership, by region
τy_{t}^{K}	Tax rate on capital income
τy_{t}^{LAB}	Tax rate on labour income
Household Transport	
τht_{t}^{CAR}	Tax rate on car purchases
τht_{t}^{DIES}	Tax rate on diesel fuel
τht_{t}^{GAS}	Tax rate on gasoline fuel
τht_{t}^{MOTO}	Tax rate on motorcycle purchases
τht_{t}^{RAIL}	Tax rate on rail trips
τht_{t}^{FOBI}	Tax rate on FOBI trips
τht_{t}^{BTM}	Tax rate on BTM trips
$bmht7_{r,rr,mot,pr,socc}^{DIES}$	Unit requirement of diesel fuel per vkm of car transport
$bmht7_{r,rr,mot,pr,socc}^{CAR}$	Unit requirement of cars per vkm of car transport
$bmht7_{r,rr,mot,pr,socc}^{GAS}$	Unit requirement of gasoline fuel per vkm of car transport

$bmht4_{r,rr,mot,pr}^{RAIL}$	Unit requirement of railway services per vkm of rail transport
$bmht4_{r,rr,mot,pr}^{MOTO}$	Unit requirement of motorcycles per vkm of motorcycle transport
$bmht4_{r,rr,mot,pr}^{BTM}$	Unit requirement of BTM services per vkm of BTM transport
$bmht4_{r,rr,mot,pr}^{FOBI}$	Unit requirement of FOBI per vkm of FOBI transport
$btht5_{r,rr,mot,pr,socc}^{CAR}$	Unit requirement of gasoline fuel per vkm of car transport
$btht4_{r,rr,mot,pr}^{RAIL}$	Unit time cost per vkm of rail transport
$btht4_{r,rr,mot,pr}^{MOTO}$	Unit time cost per vkm of motorcycle transport
$btht4_{r,rr,mot,pr}^{BTM}$	Unit time cost per vkm of BTM transport
$btht4_{r,rr,mot,pr}^{FOBI}$	Unit time cost per vkm of FOBI transport
$\alpha ht_{r,rr,mot,pr,socc}^{5a}$	Share of social mode in car transport
$\alpha ht_{r,rr,mot,pr}^{4a}$	Share of cars in private transport
$\alpha ht_{r,rr,mot,pr}^{3a}$	Share of private modes in fast transport
$\alpha ht_{r,rr,mot,pr}^{3b}$	Share of BTM modes in slow transport
$\alpha ht_{r,rr,mot,pr}^{2}$	Share of fast modes in total transport, by time period
$\alpha ht_{r,rr,mot,pr}^{1}$	Share of peak traffic in total transport
$\sigma ht_{r,rr,mot,pr}^{5a}$	elasticity of substitution between social modes
$\sigma ht_{r,rr,mot,pr}^{4a}$	elasticity of substitution between private modes
$\sigma ht_{r,rr,mot,pr}^{3a}$	elasticity of substitution between fast modes
$\sigma ht_{r,rr,mot,pr}^{3b}$	elasticity of substitution between slow modes
$\sigma ht_{r,rr,mot,pr}^{2}$	elasticity of substitution between slow and fast modes
$\sigma ht_{r,rr,mot}^{1}$	elasticity of substitution between time periods
$\varphi ht_{r,rr,mot,pr}^{5a}$	elasticity of substitution between social modes
$\varphi ht_{r,rr,mot,pr}^{4a}$	elasticity of substitution between private modes
$\varphi ht_{r,rr,mot,pr}^{3a}$	elasticity of substitution between fast modes
$\varphi ht_{r,rr,mot,pr}^{3b}$	elasticity of substitution between slow modes
$\varphi ht_{r,rr,mot,pr}^{2}$	elasticity of substitution between slow and fast modes
$\varphi ht_{r,rr,mot}^{1}$	elasticity of substitution between time periods
$\alpha_{r,rr}^{LEIS}$	share of destination regions in total leisure transport
$bcc_{r,rr}$	Work related transport requirements per commuter
Congestion	
$a_{r,rr,pr}^{TRANSIT}$	scaling parameter freight transit supply function
$\sigma_{r,rr,pr}^{TRANSIT}$	elasticity of substitution freight transit supply function
ν_m	car equivalents by road freight mode
θ_{pr}	hours per period
$\alpha_{r,rr,rrr}^{TRIPS}$	share of vkm driven on region rrr, by zone pair
a_r^{SPEED}	parameter of the regional speed-flow function
b_r^{SPEED}	parameter of the regional speed-flow function
Labour market	
$\alpha_{r,rr}^{COMM}$	
Government	
$\tau g_{g,r,t}$	Tax rate on government consumption
$\alpha_{g,gv,r}^{GOV}$	Value share of government consumption
$\alpha_{gv,g,t}^{\tau pnonelec}$	share of government in tax on non – electricity inputs
$\alpha_{gv,t}^{\tau pelec}$	share of government in tax on electricity inputs
$\alpha_{gv,g,t}^{\tau pint}$	share of government in tax on material inputs
$\alpha_{gv,g,t}^{\tau tpint}$	share of government in tax on transport material inputs
$\alpha_{gv,t}^{\tau tpcap}$	share of government in tax on transport capital services

$\alpha_{c,gv,t}^{\tau cdg,r}$	share of government in tax on durable goods
$\alpha_{c,gv,t}^{\tau cndg,r}$	share of government in tax on non-durable goods
$\alpha_{c,gv,t}^{\tau cener,r}$	share of government in tax on energy goods
$\alpha_{gv,t}^{\tau ylab}$	share of government in tax on labour
$\alpha_{gv,t}^{\tau yK}$	share of government in tax on capital
$\alpha_{gv,t}^{LST}$	share of government in lump sum tax
$\alpha_{g,r,gv,t}^{\tau i}$	share of government in tax on investment goods
$\alpha_{g,r,gv,t}^{\tau g}$	share of government in tax on government consumption
$\alpha_{gv,t}^{\tau htcar}$	share of government in tax on cars
$\alpha_{gv,t}^{\tau htdies}$	share of government in tax on diesel
$\alpha_{gv,t}^{\tau htgas}$	share of government in tax on gasoline
$\alpha_{gv,t}^{\tau htmoto}$	share of government in tax on motorcycles
$\alpha_{gv,t}^{\tau htrail}$	share of government in tax on rail services
$\alpha_{gv,t}^{\tau htBTM}$	share of government in tax on BTM
$\alpha_{gv,t}^{\tau htfobi}$	share of government in tax on fobi
$\alpha_{gv,t}^{TRF}$	share of government in transfers to household
Savings and Investment	
$\tau i_{g,r,t}$	Tax rate on investment goods
$\alpha_{g,r}^{INV}$	Value share of investment goods
φ^{INV}	Scaling parameter if investment goods

2. CGE model – list of equations

PRODUCTION

Basic prices

$PPnonelec_{s,r,g} = PA0_{r,g}\left(1 + \sum_t \tau p_{nonelec_{gt}}\right)$ where g = non-electric energy goods

$PPelec_{sr} = PA0_{r,g}\left(1 + \sum_t \tau p_{elec_t}\right)$ where g = electricity

$PPint_{gsr} = PA0_{r,g}\left(1 + \sum_t \tau p_{int_{gt}}\right)$ where g = intermediate inputs

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

$PPlab_{sr} = PP_L$

$PPtpint_{gsr} = PA0_{r,g}\left(1 + \sum_t \tau p_{tpint_{gt}}\right)$where g = transport material inputs

$PPtpcap_{sr} = PA0_{r,g}\left(1 + \sum_t \tau p_{tpcap_{gt}}\right)$where g = transport capital

Composite prices

$PPnonelecT_{sr}\, XPnonelecT_{sr} = \sum_g PPnonelec_{gsr}\, XPnonelec_{gsr}$

$PPenergy_{sr}\, XPenergy_{sr} = PPnonelecT_{sr}\, XPnonelecT_{sr} + PPelec_{sr} XPelec_{sr}$

$PPintT_{sr}\, XPintT_{sr} = \sum_g PPint_{gsr}\, XPint_{gsr}$

$PPtpintT_{sr}\, XPtpintT_{sr} = \sum_g PPpint_{gsr}\, XPtpint_{gsr}$

$PPcapen_{sr}\, XPcapen_{sr} = PPenergy_{sr}\, XPenergy_{sr} + PPcap_{sr} XPcap_{sr}$

$PPlabint_{sr}\, XPlabint_{sr} = PPintT_{sr}\, XPintT_{sr} + PPlab_{sr}\, XPlab_{sr}$

$PPklem_{sr}\, XPklem_{sr} = PPcapen_{sr}\, XPcapen_{sr} + PPlabint_{sr}\, XPlabint_{sr}$

$PPtpinp_{sr}\, XPtpinp_{sr} = PPtpintT_{sr}\, XPtpintT_{sr} + PPtpcap_{sr}\, XPtpcap_{sr}$

$PPtklem_{sr}\, XPtklem_{sr} = PPklem_{sr}\, XPklem_{sr} + PPtpinp_{sr}\, XPtpinp_{sr}$

$PPtot_{sr}\, XVPtot_{sr}\left(1 - \tau p_{prod_{s,r,t}} + sp_{prod_{s,r,t}}\right) = PPtklem_{sr}\, XPtklem_{sr}$

Quantities

$XPnonelec_{gsr} = \alpha p^{6aa}_{g,s,r}\, XPnonelecT_{sr}$

$XPnonelecT_{sr} = XPenergy_{sr}\,(1 - \alpha p^{5aa}_{s,r})\left(\frac{PPenergy_{sr}}{PPnonelecT_{sr}}\right)^{\sigma p^{4a}_{s,r}} \varphi p^{4a\ \sigma p^{4a}_{s,r}-1}_{s,r}$

$$XPelec_{sr} = XPenergy_{sr}\, \alpha p^{5aa}_{s,r} \left(\frac{PPenergy_{sr}}{Pelec_{sr}}\right)^{\sigma p^{4a}_{s,r}} \varphi p^{4a\,\sigma p^{4a}_{s,r}-1}_{s,r}$$

$$XPint_{gsr} = \alpha p^{5abb}_{g,s,r}\, XPintT_{sr}$$

$$XPenergy_{sr} = XPcapen_{sr}\,(1-\alpha p^{4a}_{s,r}) \left(\frac{PPcapen_{sr}}{PPenergy_{sr}}\right)^{\sigma p^{3a}_{s,r}} \varphi p^{3a\,\sigma p^{3a}_{s,r}-1}_{s,r}$$

$$XPcap_{sr} = XPcapen_{sr}\, \alpha p^{4a}_{s,r} \left(\frac{PPcapen_{sr}}{PPcap_{sr}}\right)^{\sigma p^{3a}_{s,r}} \varphi p^{3a\,\sigma p^{3a}_{s,r}-1}_{s,r}$$

$$XPlab_{sr} = XPlabint_{sr}\, \alpha p^{4b}_{s,r} \left(\frac{PPlabint_{sr}}{PPlab_{sr}}\right)^{\sigma p^{3b}_{s,r}} \varphi p^{3b\,\sigma p^{3b}_{s,r}-1}_{s,r}$$

$$XPintT_{sr} = XPlabint_{sr}\,(1-\alpha p^{4b}_{s,r}) \left(\frac{PPlabint_{sr}}{PPlintab_{sr}}\right)^{\sigma p^{3b}_{s,r}} \varphi p^{3b\,\sigma p^{3b}_{s,r}-1}_{s,r}$$

$$XPcapen_{sr} = XPklem_{sr}\, \alpha p^{3a}_{s,r} \left(\frac{PPklem_{sr}}{PPcapen_{sr}}\right)^{\sigma p^{2}_{s,r}} \varphi p^{2}_{s,r}{}^{\sigma p^{2}_{s,r}-1}$$

$$XPlabint_{sr} = XPklem_{sr}\,(1-\alpha p^{3a}_{s,r}) \left(\frac{PPklem_{sr}}{PPlabint_{sr}}\right)^{\sigma p^{2}_{s,r}} \varphi p^{2}_{s,r}{}^{\sigma p^{2}_{s,r}-1}$$

$$XPtpint_{gsr} = \alpha p^{4ba}_{s,r}\, XPtpintT_{sr}$$

$$XPtpintT_{sr} = \alpha p^{3ba}_{s,r}\, XPtpinp_{sr}$$

$$XPtpcap_{sr} = \left(1- \alpha p^{3ba}_{s,r}\right) XPtpinp_{sr}$$

$$XPtpinp_{sr} = XPtklem_{sr}\,(1-\alpha p^{2}_{s,r}) \left(\frac{PPtklem_{sr}}{PPtpinp_{sr}}\right)^{\sigma p^{1}_{s,r}} \varphi p^{1}_{s,r}{}^{\sigma p^{1}_{s,r}-1}$$

$$XPklem_{sr} = XPtklem_{sr}\, \alpha p^{2}_{s,r} \left(\frac{PPtklem_{sr}}{PPklem_{sr}}\right)^{\sigma p^{1}_{s,r}} \varphi p^{1}_{s,r}{}^{\sigma p^{1}_{s,r}-1}$$

$$XVPtot_{sr}\left(1-\tau p_{prod_{s,r,t}} + sp_{prod_{s,r,t}}\right) = XPtklem_{sr}$$

$$XVPtot_{sr} = \sum_{grr} XT1com_{r,rr,g}\; map_{gsr} + \sum_{r,rr,g,l,pr} XT6Road_{r,rr,g,l,pr} mt6Road_{r,rr,g,l,pr} map_{gsr}\, \alpha Road_{r} + \sum_{r,rr,g,l,pr} XT6Iww_{r,rr,g,l,pr}\; mt6Iww_{r,rr,g,l,pr}\; map_{gsr}\; \alpha Iww_{r} + \sum_{r,rr,g,l,pr} XT6Rail_{r,rr,g,l,pr} mt6Rail_{r,rr,g,l,pr} map_{gsr} \alpha Rail_{r} + \sum_{r,rr,g,l,pr} XT2Serv_{r,rr,g} map_{gsr} + \sum_{r,rr,g,l,pr} XT6Road_{r,rr,g,l,pr} TT6Road_{r,rr,g,l,pr} map_{gsr} + \sum_{r,rr,g,l,pr} XT6Rail_{r,rr,g,l,pr} tt6Road_{r,rr,g,l,pr} map_{gsr} + \sum_{r,rr,g,l,pr} XT6Iww_{r,rr,g,l,pr} tt6Iww_{r,rr,g,l,pr} map_{gsr}$$

TRADE

Basic Prices

$PA2_{r,rr,g} = PT0Good_{r,rr,g}$ if r = domestic regions

$PA1EU_{rr,r,g} = PT0Good_{r,rr,g}$ if rr = 'EU'

$PA1Row_{rr,r,g} = PT0Good_{r,rr,g} + \tau_m GDPDEF$ if rr = 'Row'

$PT2Serv_{r,rr,g} = \sum_s PPtot_{sr} map_{gg,s,r}$ if gg=market services

$PT1good_{r,rr,g} = \sum_s PPtot_{sr} map_{gsr}$ if r = domestic region

$PT1good_{r,rr,g} = p_g^{abr} ER$ if r = foreign legion

$PMT6HDV_{r,rr,g,l,pr} = \sum_{s,rrr} PPtot_{sr} map_{gg,s,rrr} \alpha Road_{rrr}$ if gg = road freight services

$PMT6LDV_{r,rr,g,l,pr} = \sum_{s,rrr} PPtot_{sr} map_{gg,s,rrr} \alpha Road_{rrr}$ if gg = road freight services

$PMT6Rail_{r,rr,g,l,pr} = \sum_{s,rrr} PPtot_{sr} map_{gg,s,rrr} \alpha Rail_{rrr}$ if gg = Rail freight services

$PMT6Iww_{r,rr,g,l,pr} = \sum_{s,rrr} PPtot_{sr} map_{gg,s,rrr} \alpha Iww_{rrr}$ if gg = Internal waterway services

$PTT6HDV_{r,rr,g} = \sum_s PPtot_{sr} map_{gg,s,r}$ if gg=market services

$PTT6LDV_{r,rr,g} = \sum_s PPtot_{sr} map_{gg,s,r}$ if gg=market services

$PTT6Iww_{r,rr,g} = \sum_s PPtot_{sr} map_{gg,s,r}$ if gg=market services

$TT6_{m,r,rr,g,l,pr} = btt6_{m,r,rr,g,l,pr} / SPEED_{r,rr,pr}$ if gg=market services

Composite Prices

$PT6_{m,r,rr,g,l,pr} = PMT6_{m,r,rr,g,l,pr}\, bmt6_{m,r,rr,g,l,pr} + PTT6_{m,r,rr,g,l,pr}\, TT6_{m,r,rr,g,l,pr}$

$PT5Road_{m,r,rr,g,l} = PT6Road_{m,r,rr,g,l,pr}$ if l = 'abroad' and pr = 'off – peak'

$PT5Rail_{r,rr,g,l} = PT6Rail_{r,rr,g,l,pr}$ if pr = 'off – peak'

$PT5Iww_{r,rr,g,l} = PT6Iww_{r,rr,g,l,pr}$ if pr = 'off – peak'

$PT5Road_{m,r,rr,g,l} XT5Road_{m,r,rr,g,l} = \sum_{pr} PT6Road_{m,r,rr,g,l,pr}\, XT6Road_{m,r,rr,g,l,pr}$

$PT4Road_{m,r,rr,g} XT4Road_{m,r,rr,g} = \sum_l PT5Road_{m,r,rr,g,l}\, XT5Road_{m,r,rr,g,l}$

$PT4Rail_{r,rr,g} XT4Rail_{r,rr,g} = \sum_l PT5Rail_{r,rr,g,l}\, XT5Rail_{r,rr,g,l}$

$PT4Iww_{r,rr,g} XT4Iww_{r,rr,g} = \sum_l PT5Iww_{r,rr,g,l}\, XT5Iww_{r,rr,g,l}$

$$PT3Road_{r,rr,g}XT3Road_{r,rr,g} = \sum_m PT4Road_{m,r,rr,g}\, XT4Road_{m,r,rr,g}$$

$$PT3Railiww_{r,rr,g}XT3Railiww_{r,rr,g} = PT4Rail_{r,rr,g}\, XT4Rail_{r,rr,g} + PT4Iww_{r,rr,g}\, XT4Iww_{r,rr,g}$$

$$PT2Transport_{r,rr,g}XT2Transport_{r,rr,g} = PT3Road_{r,rr,g}XT3Road_{r,rr,g} + PT3Railiww_{r,rr,g}XT3Railiww_{r,rr,g}$$

$$PT1Freight_{r,rr,g}XT1Freight_{r,rr,g} = PT2Transport_{r,rr,g}XT2Transport_{r,rr,g} + PT2Services_{r,rr,g}XT2Services_{r,rr,g}$$

$$PT0Good_{r,rr,g}XT0Good_{r,rr,g} = PT1Freight_{r,rr,g}XT1Freight_{r,rr,g} + PT1Comm_{r,rr,g}XT1comm_{r,rr,g}$$

$$PA1Dom_{r,g}XA1Dom_{r,g} = \sum_{rr} PA2_{r,rr,g}XA2_{r,rr,g}$$

$$PA0_{r,g}XA0_{r,g} = PA1Dom_{r,g}XA1Dom_{r,g} + PA1Eu_{r,g}XA1eu_{r,g} + PA1Row_{r,g}XA1Row_{r,g}$$

Quantities

$$XT6Road_{m,r,rr,g,l,pr} = XT5Road_{m,r,rr,g,l}\alpha t^{6}_{m,r,rr,g,l,pr}\left(\frac{PT5Road_{r,rr,g,l}}{PT6Road_{m,r,rr,g,l,pr}}\right)^{\sigma t^{5Road}_{m,r,rr,g,l}} {\varphi t^{5Road}_{m,r,rr,g,l}}^{\sigma t^{5Road}_{m,r,rr,g,l}-1}$$

$$XT6Rail_{r,rr,g,l} = XT5Rail_{r,rr,g,l}$$

$$XT6Iww_{r,rr,g,l} = XT5Iww_{r,rr,g,l}$$

$$XT5Road_{m,r,rr,g,l} = XT4Road_{m,r,rr,g}\alpha t^{5Road}_{m,r,rr,g,l}\left(\frac{PT4Road_{m,r,rr,g}}{PT5Road_{m,r,rr,g,l}}\right)^{\sigma t^{4Road}_{m,r,rr,g}} {\varphi t^{4Road}_{m,r,rr,g}}^{\sigma t^{4Road}_{m,r,rr,g}}$$

$$XT5Rail_{r,rr,g,l} = XT4Rail_{r,rr,g}\alpha t^{5Rail}_{r,rr,g,l}\left(\frac{PT4Rail_{r,rr,g}}{PT5Rail_{r,rr,g,l}}\right)^{\sigma t^{4Rail}_{r,rr,g}} {\varphi t^{4Rail}_{r,rr,g}}^{\sigma t^{4Rail}_{r,rr,g}-1}$$

$$XT5Iww_{r,rr,g,l} = XT4Iww_{r,rr,g}\alpha t^{5Iww}_{r,rr,g,l}\left(\frac{PT4Iww_{r,rr,g}}{PT5Iww_{r,rr,g,l}}\right)^{\sigma t^{4Iww}_{r,rr,g}} {\varphi t^{4Iww}_{r,rr,g}}^{\sigma t^{4Iww}_{r,rr,g}-1}$$

$$XT4Road_{m,r,rr,g} = XT3Road_{r,rr,g}\alpha t^{4Road}_{m,r,rr,g}\left(\frac{PT3Road_{r,rr,g}}{PT4Road_{m,r,rr,g}}\right)^{\sigma t^{3Road}_{r,rr,g}} {\varphi t^{3Road}_{r,rr,g}}^{\sigma t^{3Road}_{r,rr,g}-1}$$

$$XT4Rail_{r,rr,g} = XT3Railiww_{r,rr,g}\alpha t^{4Railiww}_{r,rr,g}\left(\frac{PT3Railiww_{r,rr,g}}{PT4Rail_{r,rr,g}}\right)^{\sigma t^{3Railiww}_{r,rr,g}} {\varphi t^{3Railiww}_{r,rr,g}}^{\sigma t^{3Railiww}_{r,rr,g}-1}$$

$$XT4Iww_{r,rr,g} = XT3Railiww_{r,rr,g}(1-\alpha t^{4Railiww}_{r,rr,g})\left(\frac{PT3Railiww_{r,rr,g}}{PT4Iww_{r,rr,g}}\right)^{\sigma t^{3Railiww}_{r,rr,g}} {\varphi t^{3Railiww}_{r,rr,g}}^{\sigma t^{3Railiww}_{r,rr,g}-1}$$

$$XT3Railiww_{r,rr,g} = XT2Transport_{r,rr,g}(1-\alpha t^{3Transport}_{r,rr,g})\left(\frac{PT2Transport_{r,rr,g}}{PT3Railiww_{r,rr,g}}\right)^{\sigma t^{2Transport}_{r,rr,g}} {\varphi t^{2Transport}_{r,rr,g}}^{\sigma t^{2Transport}_{r,rr,g}-1}$$

$$XT3Road_{r,rr,g} = XT2Transport_{r,rr,g}\alpha t^{3Transport}_{r,rr,g}\left(\frac{PT2Transport_{r,rr,g}}{PT3Road_{r,rr,g}}\right)^{\sigma t^{2Transport}_{r,rr,g}} \varphi t^{2Transport}_{r,rr,g}{}^{\sigma t^{2Transport}_{r,rr,g}-1}$$

$$XT2Transport_{r,rr,g} = XT1Freight_{r,rr,g}\alpha t^{2Freight}_{r,rr,g}\left(\frac{PT1Freight_{r,rr,g}}{PT2Transport_{r,rr,g}}\right)^{\sigma t^{1Freight}_{r,rr,g}} \varphi t^{1Freight}_{r,rr,g}{}^{\sigma t^{1Freight}_{r,rr,g}-1}$$

$$XT2Services_{r,rr,g} = XT1Freight_{r,rr,g}(1-\alpha t^{2Freight}_{r,rr,g})\left(\frac{PT1Freight_{r,rr,g}}{PT2Services_{r,rr,g}}\right)^{\sigma t^{1Freight}_{r,rr,g}} \varphi t^{1Freight}_{r,rr,g}{}^{\sigma t^{1Freight}_{r,rr,g}-1}$$

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

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

$XT0Comm_{rr,r,g} = XA1Row_{r,g}$ if rr = 'ROW'

$XT0Comm_{rr,r,g} = XA1eu_{r,g}$ if rr = 'EU'

$XT0Comm_{r,rr,g} = XA2_{r,rr,g}$ if r and rr = domestic regions

$$XT0Comm_{r,rr,g} = bxt0Eu_{r,g}\alpha abr_{r,g}\left(\frac{pabr_g ER}{PT0_{r,g}}\right)^{\sigma abr_g}$$

$$XA2_{r,rr,g} = XA1Dom_{r,g}\alpha a^2_{r,rr,g}\left(\frac{PA1Dom_{r,g}}{PA2_{r,rr,g}}\right)^{\sigma a^1_{r,g}} \varphi a^1_{r,g}{}^{\sigma a^1_{r,g}-1}$$

$$XA1Dom_{r,g} = XA0_{r,g}\alpha a^{1dom}_{r,g}\left(\frac{PA0_{r,g}}{PA1Dom_{r,g}}\right)^{\sigma a^0_{r,g}} \varphi a^0_{r,g}{}^{\sigma a^0_{r,g}-1}$$

$$XA1Eu_{r,g} = XA0_{r,g}\alpha a^{1eu}_{r,g}\left(\frac{PA0_{r,g}}{PA1Ru_{r,g}}\right)^{\sigma a^0_{r,g}} \varphi a^0_{r,g}{}^{\sigma a^0_{r,g}-1}$$

$$XA1Row_{r,g} = XA0_{r,g}\alpha a^{1row}_{r,g}\left(\frac{PA0_{r,g}}{PA1Row_{r,g}}\right)^{\sigma a^0_{r,g}} \varphi a^0_{r,g}{}^{\sigma a^0_{r,g}-1}$$

HOUSEHOLDS

Basic Prices

$$PC_{dg,r} = \sum_g mapH_{g,dg,r} PA0_{gr}\left(1 + \sum_t \tau c_{c,t}^{dg}\right)$$

$$PC_{ndg,r} = \sum_g mapH_{g,ndg,r} PA0_{gr}\left(1 + \sum_t \tau c_{c,t}^{ndg}\right)$$

$$PC_{ener,r} = \sum_g mapH_{g,ener,r} PA0_{gr}\left(1 + \sum_t \tau c_{c,t}^{ener}\right)$$

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

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

Composite prices

$PCgoods_{c,r} Qgoods_{c,r} = \sum_{ndg} PC_{ndg,r} QCexc_{ndg,r}$ if c = 'NDG'

$PCgoods_{c,r} Qgoods_{c,r} = \sum_{ener} PC_{ener,r} QCexc_{ener,r} + \sum_{dg} PT_{dg,r} QCexc_{dg,r}$ if c = 'dgener'

$PCgoods_{c,r} = \sum_{rr} PHT_{r,rr} \alpha_{r,rr}^{LEIS}$ if c = 'LeisTP'

$$PCcomm_r QCcomm_r = \sum_c PCgoods_{c,r} QCgoods_{c,r}$$

$$PTOT_r QTOT_r = PCcomm_r QCcomm_r + PCleis_r QCLeis_r$$

Quantities

$$QCexc_{dg,r} = QCgoods_{c,r} \alpha c_{dg,c,r}^2 \left(\frac{PCgoods_{c,r}}{PC_{dg,r}}\right)^{\sigma c_{dg,r}^2} \varphi c_{dg,r}^{2\ \ \sigma c_{dg,r}^2 - 1}$$

$$QCexc_{ndg,r} = QCgoods_{c,r} \alpha c_{ndg,c,r}^2 \left(\frac{PCgoods_{c,r}}{PC_{ndg,r}}\right)^{\sigma c_{ndg,r}^2} \varphi c_{ndg,r}^{2\ \ \sigma c_{ndg,r}^2 - 1}$$

$$QCexc_{ener,r} = QCgoods_{c,r} \alpha c_{ener,c,r}^2 \left(\frac{PCgoods_{c,r}}{PC_{ener,r}}\right)^{\sigma c_{ener,r}^2} \varphi c_{ener,r}^{2\ \ \sigma h2_{ener,r} - 1}$$

$$QCexcTOT_{ener,r} = QCexc_{ener,r} + \sum_{dg} QCenerC_{dg,r}$$

$$QCenerC_{dg,r} = QCexc_{ndg,r} a_{dg,ener}$$

$$QC_{ener,r} = QCexcTOT_{ener,r} + \mu_{c,r}^{ener}$$

$$QC_{ndg,r} = QCexc_{ndg,r} + \mu_{c,r}^{ndg}$$

$$QC_{dg,r} = QCexc_{dg,r} + \mu_{c,r}^{dg}$$

$$QCgoods_{c2,r} = QCcomm_r \alpha c_{c2,r}^1 \left(\frac{PCcomm_r}{PCgoods_{c,r}}\right)^{\sigma c_r^1} \varphi c_r^{1\ \sigma c_r^1 - 1}$$

$$QLeisTP_r = QTOT_r \alpha c_r^{0LeisTP} \left(\frac{PTOT_r}{PCleis_r}\right)^{\sigma c_r^0} \varphi {c_r^0}^{\sigma c_r^0 - 1}$$

$$QCcomm_r = QTOT_r \alpha c_r^{0comm} \left(\frac{PTOT_r}{PCcomm_r}\right)^{\sigma c_r^0} \varphi {c_r^0}^{\sigma c_r^0 - 1}$$

$$QCLeis_r = QTOT_r \alpha c_r^{0Leis} \left(\frac{PTOT_r}{PCleis_r}\right)^{\sigma c_r^0} \varphi {c_r^0}^{\sigma c_r^0 - 1}$$

$$QTOT_r = \frac{Yext_r}{PTOT_r}$$

Income

$$Yext_r = PCleis_r\left(\overline{T} - ST_{TOT_r}\right) + \omega_r^K TOTCAPY\left(1 - \sum_t \tau y_t^K\right) + CPI \cdot TRF_r - CPI \cdot LST_r - SC_{TOT_r} - SAV_{H_r} - \sum_{ener} \mu_{c,r}^{ener}\ PC_{ener,r} - \sum_{ndg} \mu_{c,r}^{ndg}\ PC_{ndg,r} - \sum_{dg} \mu_{c,r}^{dg}\ PC_{dg,r}$$

$$\begin{aligned} Ydisp_r = & \left\{\sum_{rr} COMM_{r,rr} \cdot \left[PW_r\left(1 - \sum_t \tau y_t^{LAB} - \sum_t \tau y_t^{SS}\right) - CC_{TOT_r}\right]\right. \\ & \left. + \omega_r^K TOTCAPY\left(1 - \sum_t \tau y_t^K\right) + CPI \cdot TRF_r - CPI \cdot LST_r - SC_{TOT_r}\right\} \cdot (1 - sav_H) \\ & - \sum_{ener} \mu_{c,r}^{ener}\ PC_{ener,r} - \sum_{ndg} \mu_{c,r}^{ndg}\ PC_{ndg,r} - \sum_{dg} \mu_{c,r}^{dg}\ PC_{dg,r} \end{aligned}$$

$$TOTCAPY = \sum_{s,r} XPcap_{sr} PPcap_{sr}$$

$$SAV_{H_r} = \left\{\sum_{rr} COMM_{r,rr} \cdot \left[PW_r\left(1 - \sum_t \tau y_{lab_t} - \sum_t \tau y_t^{SS}\right) - CC_{TOT_r}\right] + \omega_r^K TOTCAPY\left(1 - \sum_t \tau y_t^K\right) + CPI \cdot TRF_r - CPI \cdot LST_r - SC_{TOT_r}\right\} \cdot sav_H$$

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

HOUSEHOLD TRANSPORT

Basic prices

$$PHT7_{DIES_{r,rr,mot,pr,socc}} = PC_{dies,r}(1 + \sum_t \tau ht_t^{DIES})$$

$$PHT7_{GAS_{r,rr,mot,pr,socc}} = PC_{gaso,r}(1 + \sum_t \tau ht_t^{GAS})$$

$$PMHT4_{MOTO_{r,rr,mot,pr}} = PC_{moto,r}(1 + \sum_t \tau ht_t^{MOTO})$$

$$PMHT4_{RAIL_{r,rr,mot,pr}} = PC_{rail,r}(1 + \sum_t \tau ht_t^{RAIL})$$

$$PMHT4_{FOBI_{r,rr,mot,pr}} = PC_{fobi,r}(1 + \sum_t \tau ht_t^{FOBI})$$

$$PMHT4_{BTM_{r,rr,mot,pr}} = PC_{btm,r}(1 + \sum_t \tau ht_t^{BTM})$$

$$THT5_{CAR_{r,rr,mot,pr,socc}} = btht5_{CAR_{r,rr,mot,pr,socc}}/SPEED_{r,rr,pr}$$

$$THT4_{BTM_{r,rr,mot,pr}} = btht4_{BTM_{r,rr,mot,pr}}/SPEED_{r,rr,pr}$$

Composite prices

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

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

$$PHT4_{BTM_{r,rr,mot,pr}} = PMHT4_{BTM_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,prr}} + PCleis_r THT4_{BTM_{r,rr,mot,pr}} btht4_{BTM_{r,rr,mot,pr}}$$

$$PHT4_{MOTO_{r,rr,mot,pr}} = PMHT4_{MOTO_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,prr}} + PCleis_r THT4_{MOTO_{r,rr,mot,pr}} btht4_{MOTO_{r,rr,mot,pr}}$$

$$PHT6_{CAR_{r,rr,mot,pr,socc}} = PHT7_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} + PHT7_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} + PHT7_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}}$$

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

$$PHT4_{CAR_{r,rr,mot,pr}}\ XHT4_{CAR_{r,rr,mot,pr}} = \sum_{socc} PHT5_{CAR_{r,rr,mot,pr,socc}}\ XHT5_{CAR_{r,rr,mot,pr,socc}}$$

$$PHT3_{PRIV_{r,rr,mot,pr}}\ XHT3_{PRIV_{r,rr,mot,pr}} = PHT4_{CAR_{r,rr,mot,pr}}\ XHT4_{CAR_{r,rr,mot,pr}} + PHT4_{MOTO_{r,rr,mot,pr}}\ XHT4_{MOTO_{r,rr,mot,pr}}$$

$$PHT3_{RAIL_{r,rr,mot,pr}} = PHT4_{RAIL_{r,rr,mot,pr}}$$

$$PHT3_{FOBI_{r,rr,mot,pr}} = PHT4_{FOBI_{r,rr,mot,pr}}$$

$$PHT3_{BTM_{r,rr,mot,pr}} = PHT4_{BTM_{r,rr,mot,pr}}$$

$$PHT2_{FAST\,r,rr,mot,pr}\ XHT2_{FAST\,r,rr,mot,pr} = PHT3_{PRIV\,r,rr,mot,pr}\ XHT3_{PRIV\,r,rr,mot,pr} + PHT3_{RAIL\,r,rr,mot,pr}\ XHT3_{RAIL\,r,rr,mot,pr}$$

$$PHT2_{SLOW\,r,rr,mot,pr}\ XHT2_{SLOW\,r,rr,mot,pr} = PHT3_{BTM\,r,rr,mot,pr}\ XHT3_{BTM\,r,rr,mot,pr} + PHT3_{FOBI\,r,rr,mot,pr}\ XHT3_{FOBI\,r,rr,mot,pr}$$

$$PHT1_{r,rr,mot,pr}\ XHT1_{r,rr,mot,pr} = PHT2_{SLOW\,r,rr,mot,pr}\ XHT2_{SLOW\,r,rr,mot,pr} + PHT2_{FAST\,r,rr,mot,pr}\ XHT2_{FAST\,r,rr,mot,pr}$$

$$PHT0_{r,rr,mot}\ XHT0_{r,rr,mot} = \sum_{pr} PHT1_{r,rr,mot,pr}\ XHT1_{r,rr,mot,pr}$$

Quantities

$$XHT5_{CAR\,r,rr,mot,pr,socc} = XHT6_{CAR\,r,rr,mot,pr,socc}$$

$$XHT5_{CAR\,r,rr,mot,pr,socc} = XHT4_{CAR\,r,rr,mot,pr}\,\alpha ht^{5a}_{r,rr,mot,pr,socc}\left(\frac{PHT4_{CAR\,r,rr,mot,pr}}{PHT5_{CAR\,r,rr,mot,pr,socc}}\right)^{\sigma ht^{5a}_{r,rr,mot,pr}}\ \varphi ht^{5a}_{r,rr,mot,pr}{}^{\sigma ht^{5a}_{r,rr,mot,pr}-1}$$

$$XHT4_{CAR\,r,rr,mot,pr} = XHT3_{PRIV\,r,rr,mot,pr}\,\alpha ht^{4a}_{r,rr,mot,pr}\left(\frac{PHT3_{PRIV\,r,rr,mot,pr}}{PHT4_{CAR\,r,rr,mot,pr}}\right)^{\sigma ht^{4a}_{r,rr,mot,pr}}\ \varphi ht^{4a}_{r,rr,mot,pr}{}^{\sigma ht^{4a}_{r,rr,mot,pr}-1}$$

$$XHT4_{MOTO\,r,rr,mot,pr} = XHT3_{PRIV\,r,rr,mot,pr}(1-\alpha ht^{4a}_{r,rr,mot,pr})\left(\frac{PHT3_{PRIV\,r,rr,mot,pr}}{PHT4_{MOTO\,r,rr,mot,pr}}\right)^{\sigma ht^{4a}_{r,rr,mot,pr}}\ \varphi ht^{4a}_{r,rr,mot,pr}{}^{\sigma ht^{4a}_{r,rr,mot,pr}-1}$$

$$XHT4_{RAIL\,r,rr,mot,pr} = XHT3_{RAIL\,r,rr,mot,pr}$$

$$XHT4_{BTM\,r,rr,mot,pr} = XHT3_{BTM\,r,rr,mot,pr}$$

$$XHT4_{FOBI\,r,rr,mot,pr} = XHT3_{FOBI\,r,rr,mot,pr}$$

$$XHT3_{PRIV\,r,rr,mot,pr} = XHT2_{FAST\,r,rr,mot,pr}\,\alpha ht^{3a}_{r,rr,mot,pr}\left(\frac{PHT2_{FAST\,r,rr,mot,pr}}{PHT3_{PRIV\,r,rr,mot,pr}}\right)^{\sigma ht^{3a}_{r,rr,mot,pr}}\ \varphi ht^{3a}_{r,rr,mot,pr}{}^{\sigma ht^{3a}_{r,rr,mot,pr}-1}$$

$$XHT3_{RAIL\,r,rr,mot,pr} = XHT2_{FAST\,r,rr,mot,pr}(1-\alpha ht^{3a}_{r,rr,mot,pr})\left(\frac{PHT2_{FAST\,r,rr,mot,pr}}{PHT3_{RAIL\,r,rr,mot,pr}}\right)^{\sigma ht^{3a}_{r,rr,mot,pr}}\ \varphi ht^{3a}_{r,rr,mot,pr}{}^{\sigma ht^{3a}_{r,rr,mot,pr}-1}$$

$$XHT3_{BTM\,r,rr,mot,pr} = XHT2_{SLOW\,r,rr,mot,pr}\,\alpha ht^{3b}_{r,rr,mot,pr}\left(\frac{PHT2_{SLOW\,r,rr,mot,pr}}{PHT3_{BTM\,r,rr,mot,pr}}\right)^{\sigma ht^{3b}_{r,rr,mot,pr}}\ \varphi ht^{3b}_{r,rr,mot,pr}{}^{\sigma ht^{3b}_{r,rr,mot,pr}-1}$$

$$XHT3_{FOBI_{r,rr,mot,pr}} = XHT2_{SLOW\,r,rr,mot,pr}(1-\alpha ht^{3b}_{r,rr,mot,pr})\left(\frac{PHT2_{SLOW\,r,rr,mot,pr}}{PHT3_{FOBI_{r,rr,mot,pr}}}\right)^{\sigma ht^{3b}_{r,rr,mot,pr}} \varphi ht^{3b}_{r,rr,mot,pr}{}^{\sigma ht^{3b}_{r,rr,mot,pr}-1}$$

$$XHT2_{FAST\,r,rr,mot,pr} = XHT1_{r,rr,mot,pr}\alpha ht^{2}_{r,rr,mot,pr}\left(\frac{PHT1_{r,rr,mot,pr}}{PHT2_{FAST\,r,rr,mot,pr}}\right)^{\sigma ht^{2}_{r,rr,mot,pr}} \varphi ht^{2}_{r,rr,mot,pr}{}^{\sigma ht^{2}_{r,rr,mot,pr}-1}$$

$$XHT2_{SLOW\,r,rr,mot,pr} = XHT1_{r,rr,mot,pr}(1-\alpha ht^{2}_{r,rr,mot,pr})\left(\frac{PHT1_{r,rr,mot,pr}}{PHT2_{SLOW\,r,rr,mot,pr}}\right)^{\sigma ht^{2}_{r,rr,mot,pr}} \varphi ht^{2}_{r,rr,mot,pr}{}^{\sigma ht^{2}_{r,rr,mot,pr}-1}$$

$$XHT1_{r,rr,mot,pr} = XHT0_{r,rr,mot}\alpha ht^{1}_{r,rr,mot,pr}\left(\frac{PHT0_{r,rr,mot}}{PHT1_{r,rr,mot,pr}}\right)^{\sigma ht^{1}_{r,rr,mot}} \varphi ht^{1}_{r,rr,mot}{}^{\sigma ht^{1}_{r,rr,mot}-1}$$

$XHT0_{r,rr,mot} = \omega_{LEIS_{r,rr}}\, QLeisTP_r$ 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’

$$CC_{TOT_r} = \Big(\sum_{rr,pr,socc} PHT6_{CAR\,r,rr,mot,pr,socc} XHT6_{CAR\,r,rr,mot,pr,socc} + \sum_{rr,pr} PMHT4_{RAIL\,r,rr,mot,pr} XHT4_{RAIL\,r,rr,mot,pr} + \sum_{rr,pr} PMHT4_{MOTO\,r,rr,mot,pr} bmht4_{MOTO\,r,rr,mot,pr} XHT4_{MOTO\,r,rr,mot,pr} + \sum_{rr,pr} PMHT4_{BTM\,r,rr,mot,pr} bmht4_{BTM\,r,rr,mot,pr} XHT4_{BTM\,r,rr,mot,pr} + \sum_{rr,pr} PMHT4_{FOBI\,r,rr,mot,pr} bmht4_{FOBI\,r,rr,mot,pr} XHT4_{FOBI\,r,rr,mot,pr}\Big) / \sum_{rr} COMM_{r,rr}$$

if mot = ‘work’

$$SC_{TOT_r} = \Big(\sum_{rr,pr,socc} PHT6_{CAR\,r,rr,mot,pr,socc} XHT6_{CAR\,r,rr,mot,pr,socc} + \sum_{rr,pr} PMHT4_{RAIL\,r,rr,mot,pr} XHT4_{RAIL\,r,rr,mot,pr} + \sum_{rr,pr} PMHT4_{MOTO\,r,rr,mot,pr} bmht4_{MOTO\,r,rr,mot,pr} XHT4_{MOTO\,r,rr,mot,pr} + \sum_{rr,pr} PMHT4_{BTM\,r,rr,mot,pr} bmht4_{BTM\,r,rr,mot,pr} XHT4_{BTM\,r,rr,mot,pr} + \sum_{rr,pr} PMHT4_{FOBI\,r,rr,mot,pr} bmht4_{FOBI\,r,rr,mot,pr} XHT4_{FOBI\,r,rr,mot,pr}\Big)$$

if mot = ‘school’

$$ST_{TOT_r} = \Big(\sum_{rr,pr,socc} THT5_{CAR\,r,rr,mot,pr,socc} XHT6_{CAR\,r,rr,mot,pr,socc} + \sum_{rr,pr} btht4_{RAIL\,r,rr,mot,pr} XHT4_{RAIL\,r,rr,mot,pr} + \sum_{rr,pr} THT4_{MOTO\,r,rr,mot,pr} XHT4_{MOTO\,r,rr,mot,pr} + \sum_{rr,pr} THT4_{BTM\,r,rr,mot,pr} XHT4_{BTM\,r,rr,mot,pr} + \sum_{rr,pr} btht4_{FOBI\,r,rr,mot,pr} XHT4_{FOBI\,r,rr,mot,pr}\Big)$$

if mot = ‘school’

$$LT_{TOT_r} = \left(\sum_{rr,pr,socc} THT5_{CAR_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}} + \sum_{rr,pr} btht4_{RAIL_{r,rr,mot,pr}} XHT4_{RAIL_{r,rr,mot,pr}} + \sum_{rr,pr} THT4_{MOTO_{r,rr,mot,pr}} XHT4_{MOTO_{r,rr,mot,pr}} + \sum_{rr,pr} THT4_{BTM_{r,rr,mot,pr}} XHT4_{BTM_{r,rr,mot,pr}} + \sum_{rr,pr} btht4_{FOBI_{r,rr,mot,pr}} XHT4_{FOBI_{r,rr,mot,pr}}\right)$$

if mot = 'leisTP'

$$CT_{TOT_r} = \left(\sum_{rr,pr,socc} THT5_{CAR_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}} + \sum_{rr,pr} btht4_{RAIL_{r,rr,mot,pr}} XHT4_{RAIL_{r,rr,mot,pr}} + \sum_{rr,pr} THT4_{MOTO_{r,rr,mot,pr}} XHT4_{MOTO_{r,rr,mot,pr}} + \sum_{rr,pr} THT4_{BTM_{r,rr,mot,pr}} XHT4_{BTM_{r,rr,mot,pr}} + \sum_{rr,pr} btht4_{FOBI_{r,rr,mot,pr}} XHT4_{FOBI_{r,rr,mot,pr}}\right) / \sum_{rr} COMM_{r,rr}$$

if mot = 'work'

CONGESTION

$$VKM_{SOLO_{r,rr,mot,pr}} = XHT5_{CAR_{r,rr,mot,pr,socc}}$$

$$VKM_{POOL_{r,rr,mot,pr}} = XHT5_{CAR_{r,rr,mot,pr,socc}}$$

$$VKM_{BTM_{r,rr,mot,pr}} = XHT4_{BTM_{r,rr,mot,pr}}$$

$$VKM_{MOTO_{r,rr,mot,pr}} = XHT4_{MOTO_{r,rr,mot,pr}}$$

$$VKMTransit_{r,rr,pr} = bvkmTransit_{r,rr,pr}\left(\frac{a_{r,rr,pr}^{TRANSIT}}{SPEED_{r,rr,g}}\right)^{\sigma_{r,rr,pr}^{TRANSIT}}$$

$$PCU_{m,r,rr,g,pr} = \frac{VKM_{m,r,rr,g,l,pr}\, v_m}{356\ \theta_{pr}}$$

$$PCUtransit_{r,rr,pr} = \frac{VKMTransit_{r,rr,pr}\ 2}{356\ \theta_{pr}}$$

$$PCU_{SOLO_{r,rr,mot,pr}} = \frac{VKM_{SOLO_{r,rr,mot,pr}}}{365\ \theta_{pr}}$$

$$PCU_{POOL_{r,rr,mot,pr}} = \frac{VKM_{POOL_{r,rr,mot,pr}}}{365\ \theta_{pr}}$$

$$PCU_{BTM_{r,rr,mot,pr}} = \frac{VKM_{BTM_{r,rr,mot,pr}}}{365\ \theta_{pr}}$$

$$PCU_{MOTO_{r,rr,mot,pr}} = \frac{VKM_{MOTO_{r,rr,mot,pr}}}{365\ \theta_{pr}}$$

$$ROADFLOW_{REG_{r,pr}} = \sum_r \omega_{TRIPS_{rrr,rr,r}}\ ROADFLOW_{rrr,rr,pr}$$

$$ROADFLOW_{r,rr,pr} = \sum_{mot}\left(PCU_{SOLO_{r,rr,mot,pr}} + PCU_{POOL_{r,rr,mot,pr}} + PCU_{BTM_{r,rr,mot,pr}} + PCU_{MOTO_{r,rr,mot,pr}}\right) + \sum_{g,m}\left(PCU_{m,r,rr,g,pr}\right) + PCUtransit_{r,rr,pr}$$

$$SPEED_{r,rr,pr} = \sum_{rrr} \alpha_{r,rr,rrr}^{TRIPS} SPEED_{REG_{rrr,pr}}$$

$$SPEED_{REG_{r,pr}} = a_r^{SPEED} + b_r^{SPEED} ROADFLOW_{REG_{r,pr}}$$

LABOUR MARKET

$$TOTLAB_r = \sum_{rr} COMM_{rr,r}$$

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

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

$$TOTLAB_r = \sum_s XPlab_{sr}$$

GOVERNMENT

$$TAXREVprod_{gv,t} = \sum_{g,s,r} \frac{XPnonelec_{gsr} PPnonelec_{gsr}}{\sum_t \tau p_{nonelec_{gt}}} \tau p_{nonelec_{gt}} \alpha_{gov,g,t}^{\tau p_{nonelec}} + \sum_{s,r} \frac{XPelec_{sr} PPelec_{sr}}{\sum_t \tau p_{elec_t}} \tau p_{elec_t} \alpha_{gov,t}^{\tau p_{elec}} + \sum_{g,s,r} \frac{XPint_{gsr} PPint_{gsr}}{\sum_t \tau p_{int_{gt}}} \tau p_{int_{gt}} \alpha_{gov,g,t}^{\tau p_{int}} + \sum_{g,s,r} \frac{XPtpint_{gsr} PPtpint_{gsr}}{\sum_t \tau p_{tpint_{gt}}} \tau p_{tpint_{gt}} \alpha_{gov,g,t}^{\tau p_{tpint}} + \sum_{g,s,r} \frac{XPtpcap_{sr} PPtpcap_{sr}}{\sum_t \tau p_{tpcap_{gt}}} \tau p_{tpcap_{gt}} \alpha_{gov,t}^{\tau p_{tpcap}} + \sum_{s,r} XPcap_{sr} PPK_{sr} \tau p_{K_t} \alpha_{gov,t}^{\tau p_K} + \sum_{s,r} PPtot_{sr}\, XVPtot_{sr} \tau p_{prod_{s,r,t}} \alpha_{gov,t}^{\tau p_{prod_{sr}}} - \sum_{s,r} PPtot_{sr}\, XVPtot_{sr} s_{prod_{s,r,t}} \alpha_{gov,t}^{s_{prod_{sr}}}$$

$$TAXREV_{HH_{gv,t}} = \sum_{dg,r} \frac{PC_{dg,r} QC_{dg,r}}{\sum_t \tau c_{dg,r,t}} \tau c_{dg,r,t} \alpha_{gv,t}^{\tau c_{dg,r}} + \sum_{ndg,r} \frac{PC_{ndg,r} QC_{ndg,r}}{\sum_t \tau c_{ndg,r,t}} \tau c_{ndg,r,t} \alpha_{gv,t}^{\tau c_{ndg,r}} + \sum_{ener,r} \frac{PC_{ener,r} QC_{ener,r}}{\sum_t \tau c_{ener,r,t}} \tau c_{ener,r,t} \alpha_{gv,t}^{\tau c_{ener,r}} + \sum_{rr} COMM_{r,rr}\, PW_r \tau y_{lab_t} \alpha_{gv,t}^{\tau y_{lab_t}} + \sum_r \alpha_{K_r} TOTCAPY \tau y_{K_t}\, \alpha_{gv,t}^{\tau y_{K_t}} - \sum_r CPI \cdot LST_{r_t} \alpha_{gv,t}^{LST_{r_t}}$$

$$TAXREV_{INV_{gv,t}} = \sum_{g,r} XI_{g,r}\, PA0_{g,r} \tau i_{g,r,t} \alpha_{gv,t}^{\tau i_{g,r,t}}$$

$$TAXREV_{GOV_{gv,t}} = \sum_{g,r} XG_{g,r}\, PA0_{g,r} \tau g_{g,r,t} \alpha_{gv,t}^{\tau g_{g,r,t}}$$

$$TAXREV_{HHTP_{gv,t}} = \sum_{r,rr,mot,pr\ socc} \frac{PHT7_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}}}{\sum_t \tau ht_{car,t}} \tau ht_{car,t} \alpha_{gv,t}^{\tau ht_{car,t}} + \sum_{r,rr,mot,pr\ socc} \frac{PHT7_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}}}{\sum_t \tau ht_{dies,t}} \tau ht_{dies,t} \alpha_{gv,t}^{\tau ht_{dies,t}} + \sum_{r,rr,mot,pr\ socc} \frac{PHT7_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}}}{\sum_t \tau ht_{gas,t}} \tau ht_{gas,t} \alpha_{gv,t}^{\tau ht_{gas,t}} + \sum_{r,rr,mot,pr} \frac{PMHT4_{MOTO_{r,rr,mot,pr}} bmht4_{MOTO_{r,rr,mot,pr}} XHT4_{MOTO_{r,rr,mot,pr}}}{\sum_t \tau ht_{moto,t}} \tau ht_{moto,t} \alpha_{gv,t}^{\tau ht_{moto,t}} + \sum_{r,rr,mot,pr} \frac{PMHT4_{RAIL_{r,rr,mot,pr}} bmht4_{RAIL_{r,rr,mot,pr}} XHT4_{RAIL_{r,rr,mot,pr}}}{\sum_t \tau ht_{rail,t}} \tau ht_{rail,t} \alpha_{gv,t}^{\tau ht_{rail,t}} + \sum_{r,rr,mot,pr} \frac{PMHT4_{FOBI_{r,rr,mot,pr}} bmht4_{FOBI_{r,rr,mot,pr}} XHT4_{FOBI_{r,rr,mot,pr}}}{\sum_t \tau ht_{fobi,t}} \tau ht_{fobi,t} \alpha_{gv,t}^{\tau ht_{fobi,t}} + \sum_{r,rr,mot,pr} \frac{PMHT4_{BTM_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,pr}} XHT4_{BTM_{r,rr,mot,pr}}}{\sum_t \tau ht_{btm,t}} \tau ht_{btm,t} \alpha_{gv,t}^{\tau ht_{btm,t}}$$

$$TAXREV_{TYPE_{gv,t}} = TAXREV_{GOV_{gv,t}}\, TAXREV_{GOV_{gv,t}} + TAXREV_{INV_{gv,t}}$$

$$TAXREV_{TOT_{gv}} = \sum_t TAXREV_{TYPE_{gv,t}}$$

$$GTRF_{gv} = \sum_r TRF_r \alpha_{gv}^{TRF_r} CPI$$

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

$GOVTRANSF_{gv,gvv} = bgovtransf_{gv,gvv} CPI$ if gv = regional governments

$$GOVTRANSF_{gv,gvv} = CPIbtransfrest_{gvv} + BASICGEW_{gvv} - NEGATIVE1_{gvv} - NEGATIVE2_{gvv} + SOLIDARITYGEW_{gvv} + GRANTPIT_{gvv} + GRANTVAT_{gvv} + LAMBERMONT_{gvv}$$

$$TAXLOCGEW_r = \frac{\sum_{rr} COMM_{r,rr} PW_r}{\sum_{rrr,rr} COMM_{rrr,rr} PW_{rrr}}$$

$BASICGEW_{gv} = 10319.47328 \cdot CPI \cdot GDPREAL \cdot TAXLOCGEW_r$ if gv ≈ r

$$NEGATIVE1_{gv} = bnegative1 \cdot CPI \cdot [1 + 0.91 \cdot (GDPREAL - 1)]$$

$$NEGATIVE2_{gv} = bnegative2 \cdot CPI$$

$$SOLIDARITY_{gv} = 0.001604 \cdot 3358560 \cdot \left(1 - \frac{\sum_{rr} COMM_{r,rr} PW_r / 3358560}{\sum_{rrr,rr} COMM_{rrr,rr} PW_{rrr} / 10309725}\right) \text{ if gv = 'GWAL'}$$

$$SOLIDARITY_{gv} = 0.001604 \cdot 978384 \cdot \left(1 - \frac{\sum_{rr} COMM_{r,rr} PW_r / 978384}{\sum_{rrr,rr} COMM_{rrr,rr} PW_{rrr} / 10309725}\right) \text{ if gv = 'GBXL'}$$

$$TAXLOCGEM_{gv} = \frac{\sum_{rr} COMM_{'vla',rr} PW_{rr} + 0.2 \cdot \sum_{rr} COMM_{'bxl',rr} PW_{rr}}{\sum_{rrr,rr} COMM_{rrr,rr} PW_{rrr}} \text{ if gv = 'GVLA'}$$

$$TAXLOCGEM_{gv} = \frac{\sum_{rr} COMM_{'wal',rr} PW_{rr} + 0.8 \cdot \sum_{rr} COMM_{'bxl',rr} PW_{rr}}{\sum_{rrr,rr} COMM_{rrr,rr} PW_{rrr}} \text{ if gv = 'GCFR'}$$

$$GRANTPIT_{gv} = 3143.478189 \cdot CPI \cdot GDPREAL \cdot TAXLOCGEM_{gv}$$

$$GRANTVAT_{gv} = 9169.425124 \cdot CPI \cdot 0.4309 \text{ if gv = 'GCFR'}$$

$$GRANTVAT_{gv} = 9169.425124 \cdot CPI \cdot 0.5691 \text{ if gv = 'GVLA'}$$

$$LAMBERMONT_{gv} = 1034.615876 \cdot \left(0.4 \cdot TAXLOCGEM_{gv} + 0.6 \cdot 0.5691\right) \text{ if gov = 'GVLA'}$$

$$LAMBERMONT_{gv} = 1034.615876 \cdot \left(0.4 \cdot TAXLOCGEM_{gv} + 0.6 \cdot 0.4309\right) \text{ if gov = 'GCFR'}$$

$$SAVG_{gv} = bsavg_{gv} \cdot CPI$$

$$XG1_{gv,g} = \frac{GOVBUDG_{gv} \alpha^{gv}_{g,gv,r}}{PA0_{g,r}\left(1 + \sum_t \tau g_{g,r,t}\right)}$$

SAVINGS AND INVESTMENT

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

$$INV = SAVDOM + NETINFLOW$$

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

$$PINV = \prod_{r,g}\left(\frac{PA0_{g,r}(1+\sum_t \tau i_{g,r,t})}{\alpha_{g,r}^{I}}\right)^{\alpha_{g,r}^{I}} \Big/ \varphi^{I}$$

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

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

$$GDPREAL \cdot bgdpreal = \sum_{s,r} bpptot_{s,r} XPtot_{s,r} - \sum_{gv,t}\Bigg[\sum_{gv,tg,r} XG_{g,r}\, bpa0_{g,r} \tau g_{g,r,t} \alpha_{gv,t}^{\tau g_{g,r,t}} -$$
$$\sum_{gv,tg,r} XI_{g,r}\, bpa0_{g,r} \tau i_{g,r,t} \alpha_{gv,t}^{\tau i_{g,r,t}} -$$
$$\sum_{dg,r} \frac{bpc_{dg,r} QC_{dg,r}}{\sum_t \tau c_{dg,r,t}} \tau c_{dg,r,t} \alpha_{gv,t}^{\tau c_{dg,r}} - \sum_{ndg,r} \frac{bpc_{ndg,r} QC_{ndg,r}}{\sum_t \tau c_{ndg,r,t}} \tau c_{ndg,r,t} \alpha_{gv,t}^{\tau c_{ndg,r}} -$$
$$\sum_{ener,r} \frac{bpc_{ener,r} QC_{ener,r}}{\sum_t \tau c_{ener,r,t}} \tau c_{ener,r,t} \alpha_{gv,t}^{\tau c_{ener,r}} - \sum_{g,s,r} \frac{XPnonelec_{gsr} bppnonelec_{gsr}}{\sum_t \tau p_{nonelec_{gt}}} \tau p_{nonelec_{gt}} \alpha_{gov,g,t}^{\tau p_{nonelec}} -$$
$$\sum_{s,r} \frac{XPelec_{sr} bppelec_{sr}}{\sum_t \tau p_{elec_t}} \tau p_{elec_t} \alpha_{gov,t}^{\tau p_{elec}} - \sum_{g,s,r} \frac{XPint_{gsr} bppint_{gsr}}{\sum_t \tau p_{int_{gt}}} \tau p_{int_{gt}} \alpha_{gov,g,t}^{\tau p_{int}} -$$
$$\sum_{g,s,r} \frac{XPtpint_{gsr} bpptpint_{gsr}}{\sum_t \tau p_{tpint_{gt}}} \tau p_{tpint_{gt}} \alpha_{gov,g,t}^{\tau p_{tpint}} - \sum_{g,s,r} \frac{XPtpcap_{sr} bpptpcap_{sr}}{\sum_t \tau p_{tpcap_{gt}}} \tau p_{tpcap_{gt}} \alpha_{gov,t}^{\tau p_{tpcap}} -$$
$$\sum_{r,rr,mot,pr\ socc} \frac{bpht7_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}}}{\sum_t \tau ht_{car,t}} \tau ht_{car,t} \alpha_{gv,t}^{\tau ht_{car,t}} +$$
$$\sum_{r,rr,mot,pr\ socc} \frac{bpht7_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}}}{\sum_t \tau ht_{dies,t}} \tau ht_{dies,t} \alpha_{gv,t}^{\tau ht_{dies,t}} +$$
$$\sum_{r,rr,mot,pr\ socc} \frac{bpht7_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}} XHT6_{CAR_{r,rr,mot,pr,socc}}}{\sum_t \tau ht_{gas,t}} \tau ht_{gas,t} \alpha_{gv,t}^{\tau ht_{gas,t}} +$$
$$\sum_{r,rr,mot,pr} \frac{bpmht4_{MOTO_{r,rr,mot,pr}} bmht4_{MOTO_{r,rr,mot,pr}} XHT4_{MOTO_{r,rr,mot,pr}}}{\sum_t \tau ht_{moto,t}} \tau ht_{moto,t} \alpha_{gv,t}^{\tau ht_{moto,t}} +$$
$$\sum_{r,rr,mot,pr} \frac{bpmht4_{RAIL_{r,rr,mot,pr}} bmht4_{RAIL_{r,rr,mot,pr}} XHT4_{RAIL_{r,rr,mot,pr}}}{\sum_t \tau ht_{rail,t}} \tau ht_{rail,t} \alpha_{gv,t}^{\tau ht_{rail,t}} +$$
$$\sum_{r,rr,mot,pr} \frac{bpmht4_{FOBI_{r,rr,mot,pr}} bmht4_{FOBI_{r,rr,mot,pr}} XHT4_{FOBI_{r,rr,mot,pr}}}{\sum_t \tau ht_{fobi,t}} \tau ht_{fobi,t} \alpha_{gv,t}^{\tau ht_{fobi,t}} +$$
$$\sum_{r,rr,mot,pr} \frac{bpmhtT4_{BTM_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,pr}} XHT4_{BTM_{r,rr,mot,pr}}}{\sum_t \tau ht_{btm,t}} \tau ht_{btm,t} \alpha_{gv,t}^{\tau ht_{btm,t}}\Bigg]$$

$$XA0_{r,g} =$$
$$\sum_{r,s} XPint_{r,s,g} + \sum_{r,s} XPnonelec_{r,s} + \sum_{r,s} XPelec_{r,s} + \sum_{r,s} XPtpint_{r,s,g} + \sum_{r,s} XPtpcap_{r,s,g} +$$
$$\sum_{ndg,r} QC_{ndg,r} mapH_{g,ndg,r} + \sum_{dg,r} QC_{dg,r} mapH_{g,dg,r} + \sum_{ener,r} QC_{ener,r} mapH_{g,ener,r} +$$
$$\sum_r XI1_{r,g} + \sum_{r,gv} XG_{r,gv} +$$
$$\sum_{car,r,rr,mot,pr,socc} XHT6_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} mapH_{g,car,r} +$$
$$\sum_{dies,r,rr,mot,pr,socc} XHT6_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} mapH_{g,dies,r} +$$
$$\sum_{gas,r,rr,mot,pr,socc} XHT6_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}} mapH_{g,gas,r} +$$
$$\sum_{moto,r,rr,mot,pr} XHT4_{MOTO_{r,rr,mot,pr}} bmht4_{MOTO_{r,rr,mot,pr}} mapH_{g,moto,r} +$$
$$\sum_{rail,r,rr,mot,pr} XHT4_{RAIL_{r,rr,mot,pr}} bmht4_{RAIL_{r,rr,mot,pr}} mapH_{g,rail,r} +$$
$$\sum_{btm,r,rr,mot,pr} XHT4_{BTM_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,pr}} mapH_{g,btm,r} +$$
$$\sum_{fobi,r,rr,mot,pr} XHT4_{FOBI_{r,rr,mot,pr}} bmht4_{FOBI_{r,rr,mot,pr}} mapH_{g,fobi,r}$$

$$
\begin{aligned}
&CPI \\
&= \sum_{ndg,r} PC_{ndg,r} bqc_{ndg,r} + \sum_{dg,r} PC_{dg,r} bqc_{dg,r} + \sum_{ener,r} PC_{ener,r} bqc_{ener,r} \\
&+ \sum_{r,rr,mot,pr,socc} PHT7_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} XHT7_{CAR_{r,rr,mot,pr,socc}} \\
&+ \sum_{r,rr,mot,pr,socc} PHT7_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} XHT7_{DIES_{r,rr,mot,pr,socc}} \\
&+ \sum_{r,rr,mot,pr,socc} PHT7_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}} XHT7_{GAS_{r,rr,mot,pr,socc}} \\
&+ \sum_{r,rr,mot,pr} PMHT4_{MOTO_{r,rr,mot,pr}} bmht4_{MOTO_{r,rr,mot,pr}} XHT4_{MOTO_{r,rr,mot,pr}} \\
&+ \sum_{r,rr,mot,pr} PMHT4_{RAIL_{r,rr,mot,pr}} bmht4_{RAIL_{r,rr,mot,pr}} XHT4_{RAIL_{r,rr,mot,pr}} \\
&+ \sum_{r,rr,mot,pr} PMHT4_{BTM_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,pr}} XHT4_{BTM_{r,rr,mot,pr}} \\
&+ \sum_{r,rr,mot,pr} PMHT4_{FOBI_{r,rr,mot,pr}} bmht4_{FOBI_{r,rr,mot,pr}} XHT4_{FOBI_{r,rr,mot,pr}}
\end{aligned}
$$

MATERIAL BALANCE CONSTRAINTS

$$
\begin{aligned}
XA0_{r,g} = & \sum_{r,s} XPint_{r,s,g} + \sum_{r,s} XPnonelec_{r,s} + \sum_{r,s} XPelec_{r,s} + \sum_{r,s} XPtpint_{r,s,g} + \sum_{r,s} XPtpcap_{r,s,g} \\
& + \sum_{ndg,r} QC_{ndg,r} mapH_{g,ndg,r} + \sum_{dg,r} QC_{dg,r} mapH_{g,dg,r} \\
& + \sum_{ener,r} QC_{ener,r} mapH_{g,ener,r} + \sum_{r} XI1_{r,g} + \sum_{r,gv} XG_{r,gv} \\
& + \sum_{car,r,rr,mot,pr,socc} XHT6_{CAR_{r,rr,mot,pr,socc}} bmht7_{CAR_{r,rr,mot,pr,socc}} mapH_{g,car,r} \\
& + \sum_{dies,r,rr,mot,pr,socc} XHT6_{DIES_{r,rr,mot,pr,socc}} bmht7_{DIES_{r,rr,mot,pr,socc}} mapH_{g,dies,r} \\
& + \sum_{gas,r,rr,mot,pr,socc} XHT6_{GAS_{r,rr,mot,pr,socc}} bmht7_{GAS_{r,rr,mot,pr,socc}} mapH_{g,gas,r} \\
& + \sum_{moto,r,rr,mot,pr} XHT4_{MOTO_{r,rr,mot,pr}} bmht4_{MOTO_{r,rr,mot,pr}} mapH_{g,moto,r} \\
& + \sum_{rail,r,rr,mot,pr} XHT4_{RAIL_{r,rr,mot,pr}} bmht4_{RAIL_{r,rr,mot,pr}} mapH_{g,rail,r} \\
& + \sum_{btm,r,rr,mot,pr} XHT4_{BTM_{r,rr,mot,pr}} bmht4_{BTM_{r,rr,mot,pr}} mapH_{g,btm,r} \\
& + \sum_{fobi,r,rr,mot,pr} XHT4_{FOBI_{r,rr,mot,pr}} bmht4_{FOBI_{r,rr,mot,pr}} mapH_{g,fobi,r}
\end{aligned}
$$

Annex 5 to the final report of the **LIMOBEL** project (Long run impacts of policy packages on mobility in Belgium), financed by the Belgian FPS Science Policy. (Contract SD/TM/01B)

Bureau fédéral du Plan

NOTE

LIMOBEL Annex 5

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

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Abstract - Description.

Jel Classification -

Keywords -

Acknowledgements

Tous renseignements relatif à l'objet de la présente note peut être obtenu auprès de M.Vandresse, tel.: 02/507 73 62

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1. Objectif

Cette note présente la part des dépenses pour différents types de biens dans les dépenses totales des ménages ainsi que la part des différentes catégories de revenu dans le revenu disponible des ménages. Une section est également consacrée à l'analyse de la distribution du revenu disponible des ménages. L'analyse est réalisée pour différentes classifications des ménages : par décile du revenu disponible, par Région, par niveau d'instruction du chef de ménage, par Région pour chaque niveau d'instruction du chef de ménage et par Région pour chaque décile.

L'objectif consiste à déterminer des types représentatifs de ménages (section 3) pour les intégrer dans le modèle d'équilibre général développé dans le cadre du projet LIMOBEL, et étudier la distribution des revenus pour chaque type de ménages (section 4), avant et après simulations de scénarios intégrés dans le modèle d'équilibre général.

L'analyse statistique se base sur les données de l'enquête budget des ménages (EBM) réalisée par la Direction générale Statistique et Information économique (DGSIE). Le BFP dispose des données de 2002 à 2006.

2. Données disponibles

L'enquête sur le budget des ménages récolte, à l'aide d'un questionnaire ménage (1 par ménage), d'un questionnaire individuel (un par membre du ménage) et des carnets des dépenses et des revenus, 3 types de données : les dépenses des ménages (sur un mois) pour chaque bien et service (classification COICOP), les revenus des ménages (sur un mois) par source de revenu et un ensemble de variables socioéconomiques et démographiques permettant de décrire les ménages et ses membres. Les données mensuelles sur les dépenses et les revenus sont annualisées par la DGSIE.

Cette section présente une liste non exhaustive des données disponibles dans l'enquête budget des ménages. Il s'agit des variables qui peuvent être utilisées pour définir les types de ménages à intégrer dans le modèle d'équilibre général développé dans le cadre du projet LIMOBEL. Avant de faire l'analyse des données, chaque variable a été contrôlée par le BFP afin de détecter et corriger les valeurs extrêmes (les outliers) susceptibles de biaiser les résultats de l'analyse[1].

2.1. Les variables socio-économiques et démographiques

Les classifications permettant de définir les types de ménages sont basées sur le revenu disponible du ménage et/ou des caractéristiques socio-économiques et démographiques. Six caractéristiques socio-économiques et démographiques disponibles dans l'EBM (Tableau 1) paraissent pertinentes pour définir les types de ménages. Il s'agit des Régions, du statut socioprofessionnel du chef de ménage et de son niveau d'instruction, du nombre de personnes dans le ménage, d'une typologie axée sur la densité de population (Typo 1) et d'une typologie basée sur l'accès aux transports en commun (Typo2). Une classification des ménages basée sur les trois premières caractéristiques (Région, statut socioprofessionnel et niveau d'instruction du chef de ménage) reste très générale, et moins dépendante de l'objectif de l'étude. Une classification basée, entre autre, sur le nombre de personnes dans le ménage ou l'accès au transport en commun permet de mieux cibler certains types de ménages en fonction d'un objectif désiré, à savoir le comportement des ménages en matière de mobilité. Cette note se consacre aux classifications plus générales. Une discussion sur les critères pertinents pour définir les types de ménages est présentée à la section 5.

Tableau 1 Les variables socio-économiques et démographiques

Libellé	Définitions
reg	Région (Bruxelles-Capitale, Flandre, Wallonie)
statsoc	Statut social du chef de ménage

[1] Un memo sur la détection et la correction des valeurs extrêmes est également disponible auprès de l'auteur.

Libellé	Définitions
dipl	Niveau d'instruction du chef de ménage (< secondaire, secondaire, supérieur)
np	Nombre de personnes dans le ménage (0, 1, 2, 3+)
Typo1*	Typologie 1 : urbain, semi urbain, rural
Typo2*	Typologie 2 : accès aux transports en commun (facile, moyen, difficile)

* : Les typologies (Typo1 et Typo2) ont été calculées sur base des codes INS des communes à l'aide d'une table de conversion réalisée par le Groupe d'étude de démographie appliquée (Université catholique de Louvain).

Source : EBM

2.2. Les catégories de dépenses

L'enquête sur le budget des ménages récolte les dépenses mensuelles des ménages pour chaque biens et services. Ces produits sont intégrés dans la base de données selon la classification COICOP. Pour les besoins de l'étude, les produits ont été regroupés en 23 types de biens (Tableau 2) avec une attention toute particulière pour les dépenses liées au transport et à l'énergie.

Tableau 2 Catégories de dépenses - définitions

Libellé	Définitions
Transports	
exp_carE	Equipement voiture : achat, entretiens, réparations, dépannage, stationnement…
exp_carT	Taxes liées à l'utilisation de la voiture (mise en circulation, circulation)
exp_motoE	Equipement moto : achat, entretiens, réparations
exp_motoT	Taxes liées à l'utilisation de la moto (mise en circulation, circulation)
exp_gaso	Dépenses en carburant : essence
exp_dies	Dépenses en carburant : diesel
exp_lpg	Dépenses en carburant : LPG
exp_oil	Dépenses en carburant : huile de moteur à deux temps
exp_oth_tr	Autres services de transport (taxis, avions, bateaux…)
exp_rail	Transport par chemin de fer (SNCB)
exp_BTM	Transport par autobus vicinaux et transport urbain
exp_FoBi	Achat de Bicyclettes (sauf pour enfants), pièces de rechange et frais de réparation
Biens non durables	
exp_gaz	Dépenses pour le gaz
exp_elec	Dépenses pour l'électricité
exp_ene_S	Dépenses pour combustibles solides
exp_ene_L	Dépenses pour combustibles liquides
exp_ene_oth	Autres combustibles (ménages collectifs et factures groupées)
exp_health	Dépenses pour les soins de santé
exp_text	Dépenses pour les articles d'habillement et de chaussures
exp_food	Dépenses pour l'alimentation, les boissons et le tabac
exp_NDG_oth	Dépenses pour les autres biens non durables (eau, loisir, articles ménagers, meubles…)
Biens durables	
exp_heat	Dépenses pour les gros appareils ménages
exp_DG_oth	Dépenses pour les autres biens durables : loyers

Remarque : ultérieurement, une distinction sera faite entre l'achat et les frais d'utilisation du véhicule, ainsi que pour les biens et les services appartenant à la catégorie exp_NDG_oth.

2.3. Les catégories de revenu

2.3.1. Les revenus de l'activité économique

Les revenus de l'activité économique comprennent :

- Pour les salariés : les revenus nets de l'activité principale, y compris le pécule de vacances, les primes et autres avantages monétaires.

- Pour les indépendants : le revenu net d'indépendant (estimé par le membre du ménage).

- Les avantages en nature accordés par l'employeur : montant estimé - par la DGSIE - de la valeur des avantages en nature : vêtements, repas, carburant… Pour les indépendants, les avantages en nature correspondent aux biens achetés par l'indépendant et mis à disposition du membre du ménage.

- Les revenus provenant d'une activité accessoire.

2.3.2. Les revenus du patrimoine

Les revenus du patrimoine comprennent le revenu net des biens immobiliers et le revenu net des biens mobiliers. Le revenu net des biens immobiliers inclut également le loyer fictif des propriétaires. Ce loyer fictif correspond au montant dont un propriétaire pourrait bénéficier s'il mettait son bien sur le marché locatif.

2.3.3. Les revenus des allocations sociales

Cette catégorie reprend l'ensemble des revenus provenant d'allocations sociales, à savoir les pensions, les allocations de chômage, les indemnités pour incapacité de travail, les allocations familiales et primes ainsi que les versements par la mutuelle ou les autres revenus (non repris dans cette liste) provenant d'allocations sociales.

2.3.4. Autres revenus transférés

La section des revenus transférés reprend les transferts entre familles (rentes alimentaires principalement), les indemnités reçues des assurances (assurances vie) et d'autres revenus transférés comme des gains perçus des jeux ou des primes syndicales.

2.3.5. Charges relatives aux revenus

Cette section reprend les charges relatives aux revenus de l'activité économique qui ne sont pas retenues à la source. Ces montants peuvent être négatifs ou positifs. Un montant négatif (resp. positif) signifie que le ménage doit rembourser (resp. retoucher) ce montant.

2.3.6. Le revenu disponible

Le revenu disponible est composé de la somme du revenu net de l'activité économique, du revenu net du patrimoine, du revenu des allocations sociales, des autres revenus transférés et des charges relatives aux revenus. Le revenu disponible n'inclut donc pas l'épargne du ménage.

2.3.7. Le revenu disponible équivalent

Le revenu disponible équivalent correspond au revenu disponible des ménages ajusté par la taille du ménage. Plus précisément, le revenu disponible équivalent est obtenu en divisant le revenu disponible du ménage par le nombre d'unité de consommation dans le ménage. Selon l'échelle d'équivalent modifiée de l'OCDE, le premier adulte représente une unité de consommation, chaque adulte supplémentaire compte pour 0.7 unité de consommation et chaque enfant compte pour 0.3 unité de consommation. L'objectif du revenu disponible équivalent est de pouvoir comparer les revenus disponibles des ménages de tailles différentes

2.4. L'épargne

L'épargne d'un ménage correspond à la différence entre le revenu net disponible du ménage (section 2.3) et la consommation de biens et services (section 2.2) par ce même ménage. L'épargne inclut les investissements en biens immobiliers (p. ex. achat d'une maison ou transformation) et mobiliers (actifs : actions, obligations, fonds de pension…).

3. Statistiques sur les dépenses et les revenus

La part des dépenses pour chaque type de biens et services dans les dépenses totales, ainsi que la part de chaque catégorie de revenu dans le revenu disponible des ménages sont analysées sur base de différents types de ménages. Les types de ménages sont définis sur base de 5 critères :

- les déciles du revenu disponible équivalent (10 types de ménages)
- les Régions (3 types de ménages)
- le niveau d'instruction du chef de ménage (3 types de ménages)
- le niveau d'instruction du chef de ménage par Région (9 types de ménages)
- les déciles par Région (30 types de ménages)

Avant de présenter et commenter les résultats de l'analyse descriptive pour les dépenses (section 3.2) et pour les revenus (section 3.3), une première section présente brièvement les caractéristiques (déciles, Région et niveau d'instruction du chef de ménage) qui définissent les types de ménages. L'analyse de la base de données tient compte des coefficients d'extrapolation permettant de donner des résultats représentatifs de l'ensemble des ménages résidant en Belgique.

3.1. Les types de ménages

3.1.1. Déciles

Les déciles du revenu disponible équivalent sont présentés dans le Tableau 3. A titre d'illustration, les ménages appartenant à l'échantillon de 2005 et possédant un revenu disponible équivalent inférieur à 12 430 EUR/an (Q1) appartiennent au type de ménages Q1. Ceux ayant un revenu équivalent supérieur ou égal à 12 430 EUR/an (Q1) et inférieur à 15 258 EUR/an (Q2) appartiennent au type de ménages Q2 (et ainsi de suite). Le revenu disponible équivalent est calculé sur base de l'échelle d'équivalence modifiée de l'OCDE.

Tableau 3 Déciles du revenu disponible équivalent (EUR/an)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
2002	11336	14041	16170	18316	20394	22544	25779	29884	36330
2003	11700	14424	16904	19084	21367	23661	26275	30216	36450
2004	12033	14912	17348	19557	21860	24342	27528	32048	38212
2005	12430	15258	17726	20095	22455	24908	28129	32577	39252
2006	12551	15923	18396	21000	23390	25788	28938	33054	40795
2002-2006	11966	14881	17325	19563	21869	24344	27387	31665	38247

Source : EBM 2002 – 2006.
Calculs : BFP.

3.1.2. Régions

La répartition des ménages dans l'enquête budget des ménages selon les trois Régions (Tableau 4) est conforme aux statistiques officielles de population. Ce résultat est tout à fait logique étant donné que l'extrapolation des résultats de l'enquête budget des ménages se base sur une post-stratification des ménages selon différentes variables sociodémographiques, dont la région d'habitation.

Tableau 4 Répartition des ménages (%) par Région

	RBC	FL	WA
2002	10.7	56.7	32.5
2003	10.7	56.8	32.3
2004	10.8	56.7	32.4
2005	10.8	56.3	32.7
2006	10.9	56.3	32.7

Source : EBM 2002 – 2006.
Calculs : BFP.

3.1.3. Niveau d'instruction du chef de ménage

Les statistiques présentées dans le Tableau 5 indiquent que la part des ménages dont le chef de ménage a un diplôme du niveau supérieur paraît relativement élevée (de 39.7% en 2002 à 42.6% en 2006) dans l'EBM par rapport à ce qui est généralement observé pour la population totale (de 21.6% en 2002 à 24.7% en 2006[2]). Il faut cependant tenir compte du fait que le chef de ménage est défini, dans l'enquête budget des ménages, comme étant la personne qui contribue le plus au revenu du ménage. Etant donné la corrélation entre le revenu et le niveau d'instruction, il n'est donc pas étonnant que les chefs de ménages soient davantage représentés par des personnes ayant un niveau d'instruction élevé. De plus, la distribution d'âge des chefs de ménages n'est pas identique à la distribution de la population dans son ensemble. Les chefs de ménages sont en général plus âgés (peu d'observations en dessous de 25 ans), ce qui tire également le niveau d'instruction vers le haut.

[2] Source : Direction générale Statistique et Information économique - Enquête sur les forces de travail.

Tableau 5 Répartition des ménages (%) par niveau d'instruction du chef de ménage

	< secondaire	secondaire	supérieur
2002	32.7	27.4	39.7
2003	30.7	28.6	40.5
2004	28.2	29.3	42.3
2005	30.0	27.9	42.0
2006	28.8	28.4	42.6

Source : EBM 2002 – 2006.
Calculs : BFP.

3.2. Dépenses par type de ménages

Cette section présente les parts des dépenses pour les différentes classifications de ménages. Dans un premier temps, on s'intéresse à la part des dépenses, par catégorie de biens, pour les ménages regroupés par décile (du revenu disponible équivalent). Ensuite, les résultats sont présentés par Région (Bruxelles-Capitale, Flandre, Wallonie) ainsi que par niveau d'instruction du chef de ménage. Finalement, les résultats sont également présentés par niveau d'instruction du chef de ménage dans chaque Région et par décile dans chaque Région.

Remarque : Les catégories de biens sont très hétérogènes d'un point de vue de l'agrégation des biens. Certaines catégories de biens sont en effet très détaillées (principalement pour le transport et l'énergie), alors que d'autres restent à un niveau très général (alimentation, santé, bien durables « autres »). Pour les catégories détaillées, il faut rester prudent en termes d'interprétation et de généralisation. En effet, le nombre d'observations (nombre de ménages avec une dépense supérieure à 0 EUR) pour ces catégories détaillées est moins important que pour des catégories plus générales.

3.2.1. Déciles

A la lecture du Tableau 6, une tendance générale apparaît. La part des dépenses pour les biens dits *de nécessité* diminue avec le revenu disponible. En effet, les parts des dépenses pour les dépenses en énergie (gaz, électricité), les dépenses pour l'alimentation et les dépenses pour le logement (repris dans la catégorie « autres biens durables ») diminuent lorsqu'on monte dans les déciles. En toute logique, la part des dépenses dans les dépenses totales pour les autres biens (équipement transport, vêtements, autres biens non durables) augmente avec le revenu disponible. A noter toutefois que les dépenses pour les bus, trams et métros ainsi que les dépenses pour les gros appareils ménagers varient peu en fonction du revenu. Finalement, en ce qui concerne les dépenses pour les soins de santé ainsi que pour l'essence et le diesel, on constate d'abord une augmentation de la part des dépenses suivie d'une diminution.

Tableau 6 Part des dépenses dans les dépenses totales par décile (Σ par type de ménages = 1)

	Total	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
exp_carE	0,087	0,039	0,062	0,068	0,069	0,077	0,088	0,086	0,092	0,107	0,139
exp_carT	0,007	0,007	0,008	0,007	0,008	0,007	0,008	0,009	0,009	0,008	0,008
exp_motoE	0,003	0,001	0,001	0,002	0,005	0,002	0,003	0,004	0,002	0,003	0,004
exp_motoT	0,00004	0,0000	0,0001	0,0000	0,0001	0,0001	0,0000	0,0000	0,0000	0,0000	0,0001
exp_gaso	0,012	0,012	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,012	0,010
exp_dies	0,014	0,010	0,012	0,014	0,014	0,014	0,015	0,016	0,015	0,015	0,015
exp_lpg	0,001	0,001	0,001	0,001	0,0004	0,001	0,0005	0,0004	0,0003	0,001	0,0004
exp_oil	0,0001	0,0002	0,0001	0,0002	0,0001	0,0001	0,0001	0,0002	0,0001	0,0001	0,0001
exp_rail	0,003	0,003	0,002	0,003	0,002	0,002	0,002	0,003	0,003	0,003	0,003
exp_BTM	0,002	0,004	0,002	0,002	0,002	0,002	0,001	0,002	0,001	0,001	0,001
exp_FoBi	0,002	0,001	0,002	0,002	0,002	0,002	0,002	0,003	0,003	0,003	0,002
exp_oth_tr	0,002	0,002	0,001	0,002	0,002	0,001	0,001	0,001	0,002	0,002	0,003
exp_gaz	0,017	0,023	0,019	0,019	0,018	0,015	0,016	0,015	0,016	0,014	0,015
exp_elec	0,023	0,031	0,028	0,026	0,025	0,024	0,022	0,022	0,021	0,020	0,018
exp_ene_S	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,000	0,000
exp_ene_L	0,011	0,010	0,011	0,014	0,011	0,010	0,010	0,011	0,011	0,011	0,010
exp_ene_oth	0,001	0,002	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,002
exp_health	0,045	0,045	0,052	0,053	0,053	0,050	0,050	0,044	0,041	0,040	0,034
exp_text	0,047	0,036	0,041	0,041	0,043	0,048	0,050	0,051	0,052	0,052	0,053
exp_food	0,160	0,200	0,188	0,177	0,172	0,167	0,160	0,157	0,152	0,142	0,129
exp_NDG_oth	0,331	0,284	0,299	0,307	0,321	0,332	0,333	0,345	0,345	0,356	0,348
exp_heat	0,009	0,008	0,009	0,010	0,009	0,010	0,010	0,009	0,010	0,009	0,009
exp_DG_oth	0,218	0,279	0,246	0,237	0,226	0,220	0,212	0,207	0,209	0,201	0,196

Source : EBM 2002-2006.
Calculs : BFP.

3.2.2. Régions

De manière générale (Tableau 7), les ménages de la Région de Bruxelles-Capitale se distinguent par des parts de dépenses plus élevées pour les transports en commun (Bus, Tram, Metro) – 0.5%-, l'équipement moto – 0.4% -, le gaz – 2.1%- et les dépenses pour le logement -25.9%- Les ménages habitant en Flandre se caractérisent davantage par des parts de dépenses plus élevées pour les biens non durables 'autres' -33.7%- le vélo -0.3%- et les vêtements -5.1%- Finalement, les ménages wallons sont caractérisés par des parts de dépenses plus élevées pour le diesel -1.7%-, l'électricité -2.6%-, les combustibles liquides -1.8%- et l'alimentation – 16%.

Un intervalle de confiance[3] pour chaque part des dépenses a été calculé. Ce qui permet de déterminer si les parts de dépenses par Région sont statistiquement différentes l'une de l'autre. Plus précisément, le test consiste à déterminer si les intervalles de confiance pour la part de dépense du bien g sont différents selon les Régions. Les valeurs statistiquement significatives sont représentées dans le Tableau 9 par des astérisques.

[3] Intervalle de confiance (seuil de 0.05%) = $x \pm \ .96 * SE$ (SE = écart-type).

Sur base des intervalles, les ménages wallons consacrent des parts de dépense plus importante (par rapport à Bruxelles-Capitale et à la Wallonie) pour l'électricité, et les autres énergies solides et liquides ainsi que pour le diesel et l'alimentation. Les parts des dépenses pour le gaz et les autres formes d'énergie sont significativement plus faibles qu'en Flandre et à Bruxelles. Pour le gaz, la part des dépenses est également plus faible en Flandre par rapport à Bruxelles. En ce qui concerne les carburants, tant les ménages wallons que les ménages flamands dépensent davantage que les ménages bruxellois (sans différence statistiquement significative entre les ménages flamands et les ménages wallons). Une exception est cependant observée pour le diesel dont la part des dépenses est statistiquement plus importante en Wallonie qu'en Flandre.

Tableau 7 Part des dépenses dans les dépenses totales par Région (Σ par type de ménages = 1)

	Total	RBC	FL	WA
exp_carE	0,087	0,077	0,088	0,089
exp_carT	0,007	0,005*	0,008	0,008
exp_motoE	0,003	0,004	0,003	0,003
exp_motoT	0,00004	0,00002	0,00006	0,00003
exp_gaso	0,012	0,010*	0,014	0,013
exp_dies	0,014	0,006*	0,014*	0,017*
exp_lpg	0,001	0,0001*	0,0005	0,001
exp_oil	0,0001	0,00001*	0,0002	0,0001
exp_rail	0,003	0,003	0,003	0,003
exp_BTM	0,002	0,005*	0,001	0,002
exp_FoBi	0,002	0,001	0,003*	0,001
exp_oth_tr	0,002	0,005*	0,002	0,001
exp_gaz	0,017	0,021*	0,017*	0,014*
exp_elec	0,023	0,019*	0,022*	0,026*
exp_ene_S	0,001	0,000	0,000	0,001*
exp_ene_L	0,011	0,003*	0,008*	0,018*
exp_ene_oth	0,001	0,003*	0,001	0,001
exp_health	0,045	0,048	0,044*	0,048
exp_text	0,047	0,044	0,051*	0,043
exp_food	0,160	0,155	0,159	0,165*
exp_NDG_oth	0,331	0,324	0,337*	0,323
exp_heat	0,009	0,007*	0,009	0,010
exp_DG_oth	0,218	0,259*	0,215	0,213

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions.

Source : EBM 2002-2006.

Calculs : BFP.

3.2.3. Niveau d'instruction du chef de ménage

Les tendances générales observées dans le Tableau 8 exposant la part des dépenses pour chaque catégorie de bien par niveau d'instruction du chef de ménage sont identiques à celles mentionnées à la section 3.2.1 sur la part des dépenses par décile du revenu disponible équivalent. Cette relation s'explique par la forte corrélation entre le niveau d'instruction du chef de ménage et le revenu disponible du ménage. On observe ainsi une part des dépenses pour les biens de *nécessité* (gaz, électricité, alimentation et logement) qui diminue avec le niveau d'instruction. Pour les autres biens (équipement voiture, vêtements, biens non durables « autres »), la part des dépenses augmente avec le niveau d'instruction du chef de ménage. Les différences entre les Régions sont statistiquement significatives principalement pour les dépenses liées à l'énergie, aux vêtements, à l'alimentation et aux biens durables et non durables de type « autres ».

Tableau 8 Part des dépenses dans les dépenses totales par niveau d'instruction du chef de ménage (Σ par type de ménages = 1)

	Total	< secondaire	secondaire	supérieur
exp_carE	0,087	0,067	0,083	0,100**
exp_carT	0,007	0,008	0,008	0,007
exp_motoE	0,003	0,002	0,005	0,003
exp_motoT	0,00004	0,00006	0,00005	0,00004
exp_gaso	0,012	0,013	0,014	0,013
exp_dies	0,014	0,012*	0,014	0,015
exp_lpg	0,001	0,0003*	0,001	0,001
exp_oil	0,0001	0,0002	0,0001	0,0001**
exp_rail	0,003	0,002	0,002	0,003**
exp_BTM	0,002	0,001	0,002	0,002
exp_FoBi	0,002	0,002	0,002	0,003
exp_oth_tr	0,002	0,001	0,001	0,002*
exp_gaz	0,017	0,019*	0,016	0,015
exp_elec	0,023	0,027*	0,024*	0,021*
exp_ene_S	0,001	0,001*	0,0005	0,0004
exp_ene_L	0,011	0,014*	0,010	0,010
exp_ene_oth	0,001	0,001	0,001	0,001
exp_health	0,045	0,055*	0,045*	0,041*
exp_text	0,047	0,038*	0,047*	0,053*
exp_food	0,160	0,180*	0,166*	0,148*
exp_NDG_oth	0,331	0,305*	0,327*	0,347*
exp_heat	0,009	0,009	0,009	0,009
exp_DG_oth	0,218	0,243*	0,221*	0,205*

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée pour les deux autres niveaux d'instruction. ** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée pour un niveau d'instruction inférieur au niveau secondaire.

Source : EBM 2002-2006.

Calculs : BFP.

3.2.4. Régions par niveau d'instruction

Calculer des parts de dépenses par Région pour chaque niveau d'instruction sous-entend qu'on émette l'hypothèse que, pour un même niveau d'instruction du chef de ménage, la part des dépenses pour chaque catégorie de bien varie selon la Région.

L'intervalle de confiance pour chaque part des dépenses a été calculé. Pour un même niveau d'instruction du chef de ménage, des différences régionales persistent. Bien que tous les résultats ne soient pas significatifs, la part des dépenses pour les ménages habitant en Flandre et en Wallonie reste plus importante pour le transport (équipement et taxes pour la voiture, diesel et essence). Par leur situation géographique, les ménages bruxellois, quel que soit le niveau d'instruction du chef de ménage, maintiennent un part des dépenses plus importante pour les transports en commun (bus, tram, métro). La Flandre maintient également une part des dépenses plus importante pour le vélo. En ce qui concerne l'énergie, une part des dépenses pour le gaz (resp. l'électricité) plus élevée pour les ménages bruxellois (resp. wallons) est encore observée; et ce quel que soit le niveau d'instruction du chef de ménage. Finalement, pour les autres biens de consommation, la différence la plus marquante se situe au niveau des dépenses pour les autres biens de consommation durables (le logement). Ce sont les ménages bruxellois qui consacrent une plus grande partie de leurs dépenses à ce type de bien, à nouveau quelque soit le niveau d'instruction du chef de ménage

Tableau 9 Part des dépenses dans les dépenses totales par Région et par niveau d'instruction du chef de ménage (Σ par type de ménages = 1)

	< secondaire			secondaire			supérieur		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
exp_carE	0,052	0,067	0,071	0,071	0,087	0,077	0,086	0,100	0,106
exp_carT	0,003*	0,010	0,007	0,004*	0,009	0,008	0,006	0,008	0,008
exp_motoE	0,001	0,002	0,002	0,013	0,004	0,003	0,001	0,003	0,002
exp_motoT	0	0,0001	0,00004	0	0,00007	0,00003	0,00003	0,00004	0,00003
exp_gaso	0,009*	0,014	0,012	0,009*	0,014	0,014	0,010*	0,013	0,013
exp_dies	0,004*	0,012*	0,014*	0,006*	0,014*	0,017*	0,007*	0,015*	0,019*
exp_lpg	0,0001	0,0002	0,0005**	0,0000*	0,0006	0,0008	0,0001*	0,0005	0,0007
exp_oil	0,00001*	0,0002	0,0002	0,0000*	0,0002	0,0001	0,0000*	0,0001	0,0001
exp_rail	0,002	0,001	0,002	0,002	0,002	0,002	0,004	0,004	0,003
exp_BTM	0,005*	0,001*	0,002*	0,005*	0,001*	0,002*	0,005*	0,001	0,002
exp_FoBi	0,000	0,003*	0,000	0,000	0,003*	0,001	0,002	0,004*	0,001
exp_oth_tr	0,002	0,001	0,001	0,004*	0,001	0,001	0,007*	0,002	0,001
exp_gaz	0,026*	0,019*	0,017*	0,022*	0,017*	0,014*	0,019*	0,016*	0,013*
exp_elec	0,022*	0,025*	0,030*	0,020*	0,023*	0,027*	0,017*	0,021*	0,023*
exp_ene_S	0,001	0,001	0,002*	0,00007*	0,0005	0,001	0,000	0,000	0,001**
exp_ene_L	0,003*	0,011*	0,020*	0,004*	0,007*	0,018*	0,003*	0,007*	0,017*
exp_ene_oth	0,004*	0,001	0,001	0,003*	0,001	0,001	0,002*	0,001	0,001
exp_health	0,056	0,054	0,055	0,048	0,043	0,049	0,045	0,039*	0,044
exp_text	0,043	0,040	0,035*	0,039	0,050*	0,043	0,046	0,057*	0,048
exp_food	0,186	0,177	0,183	0,163	0,162	0,173***	0,144	0,147	0,150
exp_NDG_oth	0,276	0,313*	0,298	0,302	0,334*	0,319	0,346	0,350	0,341
exp_heat	0,007	0,009	0,009	0,009	0,008	0,011	0,006*	0,009	0,011
exp_DG_oth	0,297*	0,239	0,237	0,275*	0,217	0,217	0,243*	0,202	0,196

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions. ** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale. *** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en Région Flamande.

Source : EBM 2002-2006.
Calculs : BFP.

3.2.5. Régions par décile

Dans une perspective d'analyse régionale, il est opportun d'étudier les parts des dépenses pour chaque type de biens par Région pour chaque décile du revenu disponible. L'objectif consiste alors à déterminer si les comportements en termes de dépenses pour les ménages appartenant à un même décile du revenu sont différents selon les Régions. Les résultats sont présentés dans le Tableau 10.

Sur base de cette hypothèse, 30 types de ménages sont considérés ; ce qui diminue le nombre d'observations pour chaque catégorie de biens par type de ménages et par conséquent diminue également la fiabilité des résultats. Pour certaines cellules, on obtient d'ailleurs aucune information (p.ex. pas de dépense pour le LPG pour les ménages habitant dans la région de Bruxelles-Capitale et appartenant aux déciles Q2 et Q3). Si on souhaite maintenir une analyse à ce niveau (30 types de ménages) il faut alors imputer des parts de dépenses aux cellules qui ne contiennent aucune dépense. Ce sont en effet des dépenses nulles dues à l'échantillonnage, et non à un comportement réel des ménages.

Afin de déterminer la pertinence de ces 30 types de ménages, l'intervalle de confiance pour chaque part des dépenses a été calculé. Les valeurs statistiquement significatives sont représentées dans le Tableau 10 par un astérisque. De manière générale, les résultats significatifs se situent davantage pour les biens de consommation liés au transport et à l'énergie. Quelques différences statistiquement significatives sont observées pour les parts des dépenses liées à la santé, à l'alimentation, aux vêtements, aux biens durables et non durables 'autres'.

Tableau 10 Part des dépenses dans les dépenses totales par Région et par décile du revenu disponible équivalent (Σ par type de ménages = 1)

	Q1			Q2			Q3			Q4			Q5		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
exp_carE	0,029	0,049	0,033	0,049	0,060	0,068	0,097	0,060	0,074	0,067	0,061	0,085	0,063	0,068	0,094
exp_carT	0,003	0,008	0,007	0,008	0,010	0,005	0,004	0,008	0,007	0,006	0,009	0,007	0,005	0,005	0,009
exp_motoE	0,000	0,001	0,001	0,000	0,002	0,000	0,001	0,002	0,003	0,002	0,006	0,005	0,002	0,003	0,001
exp_motoT	0	0	0	0	0,000	0,0001	0	0,000	0,000	0	0,000	0	0	0,000	0,0001
exp_gaso	0,007*	0,013	0,012	0,009*	0,014	0,015	0,010*	0,014	0,014	0,010*	0,014	0,014	0,011	0,014	0,013
exp_dies	0,006*	0,011	0,011	0,004*	0,011	0,016	0,006*	0,014	0,016	0,006*	0,013*	0,018*	0,005*	0,014*	0,017*
exp_lpg	0,000	0,001	0,001	0	0,000	0,001	0	0,001	0,001	0,000*	0,000	0,001	0,000	0,001	0,001
exp_oil	0	0,000	0,000	0	0,000	0,000	0,000	0,000	0,000	0	0,000	0,000	0	0,000	0,000
exp_rail	0,006*	0,003	0,003	0,003	0,002	0,001	0,002	0,003	0,002	0,003	0,003	0,002	0,002	0,002	0,002
exp_BTM	0,008*	0,002	0,004	0,006*	0,002	0,002	0,007*	0,001	0,002	0,007*	0,001	0,002	0,005*	0,001	0,002
exp_Fobi	0,001	0,003	0,001***	0,001	0,003*	0,001	0,001	0,002*	0,001	0,000	0,004*	0,000	0,001	0,003*	0,001
exp_oth_tr	0,003	0,002	0,002	0,003	0,001	0,001	0,005	0,002	0,001	0,005	0,002	0,001	0,005*	0,001	0,001
exp_gaz	0,030*	0,021	0,022	0,025*	0,019	0,018	0,022	0,020	0,018	0,021	0,019	0,016	0,020***	0,017	0,013
exp_elec	0,027	0,030	0,034*	0,022*	0,026*	0,031*	0,021*	0,026	0,028	0,020*	0,025	0,027	0,018*	0,025	0,025
exp_Ene_S	0,000	0,000	0,002*	0,000*	0,001	0,002	0,000*	0,000	0,001	0,000*	0,001	0,001	0,000*	0,001	0,001
exp_Ene_L	0,004	0,006	0,017*	0,006	0,008	0,018*	0,002*	0,013	0,019	0,002	0,008*	0,020*	0,002*	0,008	0,015
exp_Ene_oth	0,004*	0,000*	0,002*	0,005	0,001	0,001	0,004*	0,001	0,001	0,002	0,002	0,001	0,002	0,001	0,001
exp_health	0,040	0,042	0,050	0,057	0,050	0,053	0,047	0,054	0,053	0,057	0,050	0,059	0,059	0,048	0,051
exp_text	0,044	0,0336	0,036	0,0333	0,044*	0,0380	0,033	0,0440	0,037	0,046	0,046	0,037***	0,043	0,052	0,042***
exp_food	0,197	0,196	0,205	0,185	0,187	0,191	0,164	0,178	0,178	0,152*	0,175	0,173	0,160	0,167	0,168
exp_NDG_oth	0,258*	0,296	0,284	0,286	0,311	0,283***	0,288	0,311	0,307	0,326	0,328	0,306	0,326	0,338	0,322
exp_heat	0,005	0,009	0,008	0,007	0,009	0,008	0,006	0,009	0,012	0,008	0,009	0,008	0,009	0,009	0,012
exp_DG_oth	0,329*	0,271	0,265	0,291*	0,237	0,247	0,281*	0,238	0,225	0,259*	0,226	0,217	0,263*	0,221	0,208

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions. ** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale. *** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en Région Flamande.

Source : EBM 2002-2006. Calculs : BFP.

Tableau 10 (suite) Part des dépenses dans les dépenses totales par Région et par décile du revenu disponible équivalent (Σ par type de ménages = 1)

	Q6			Q7			Q8			Q9			Q10		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
exp_carE	0,073	0,090	0,090	0,056	0,091	0,083	0,092	0,093	0,093	0,108	0,103	0,115	0,108	0,148	0,133
exp_carT	0,006	0,008	0,008	0,004	0,009	0,009	0,007	0,010	0,009	0,004	0,008	0,009	0,005	0,010**	0,007
exp_motoE	0,005	0,002	0,006	0,028	0,002	0,002	0,000	0,002	0,001	0,000	0,004	0,002	0,002	0,006	0,003
exp_motoT	0	0,000	0,000	0	0,000	0,000	0	0,000	0	0	0,000	0	0.000	0,000	0
exp_gaso	0,011	0,015	0,013	0,012	0,014	0,015	0,011	0,014	0,014	0,010	0,013*	0,012	0,008	0,010	0,010
exp_dies	0,006*	0,015	0,019	0,007*	0,016	0,018	0,006*	0,015*	0,019*	0,007*	0,015	0,017	0,008*	0,015	0,018
exp_lpg	0,000	0,001	0,000	0	0,000	0,001	0,000	0,000	0,000	0,000*	0,001	0,001	0,000	0,001	0,000
exp_oil	0,000	0,000	0,000	0,000*	0,000	0,000	0	0,000	0,000	0,000	0,000	0,000	0,000*	0,000	0,000
exp_rail	0,002	0,003	0,002	0,002	0,003	0,004	0,003	0,003	0,002	0,003	0,003	0,003	0,004	0,002*	0,004
exp_BTM	0,004*	0,001	0,002	0,006*	0,001*	0,002*	0,004*	0,001	0,001	0,003*	0,001	0,001	0,003*	0,001	0,001
exp_Fobi	0,002	0,003	0,001***	0,001	0,004	0,001***	0,001	0,003*	0,001	0,001	0,004*	0,001	0,002	0,003	0,001
exp_oth_tr	0,004*	0,001	0,001	0,004*	0,001	0,000	0,004	0,002	0,001	0,007***	0,002	0,001	0,010*	0,003	0,002***
exp_gaz	0,019	0,017	0,012*	0,021*	0,016	0,013	0,019	0,017	0,012*	0,018***	0,015	0,011	0,018*	0,015	0,013
exp_elec	0,019*	0,022*	0,024*	0,017*	0,022	0,024	0,017*	0,020*	0,024*	0,016*	0,020*	0,022*	0,015	0,018	0,020
exp_Ene_S	0,000	0,001	0,001	0,000	0,001	0,001	0,000	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000*
exp_Ene_L	0,002*	0,008*	0,017*	0,003*	0,009	0,018	0,004	0,007	0,021*	0,002*	0,007*	0,022*	0,005***	0,009	0,015
exp_Ene_oth	0,002***	0,000	0,001	0,003***	0,001	0,001	0,004	0,000	0,001	0,002	0,001	0,001	0,002	0,002	0,002
exp_health	0,048	0,051	0,049	0,048	0,041	0,049	0,041	0,039	0,046	0,045	0,039	0,041	0,044	0,032**	0,035
exp_text	0,043	0,053	0,045	0,051	0,051	0,049	0,0465	0,055	0,0482	0,047	0,056	0,045***	0,046	0,056	0,051
exp_food	0,157	0,158	0,164	0,158	0,157	0,157	0,150	0,150	0,159	0,134	0,141	0,147	0,127	0,128	0,131
exp_NDG_oth	0,342	0,330	0,336	0,329	0,346	0,345	0,336	0,352	0,334	0,353	0,362	0,340	0,357	0,344	0,353
exp_heat	0,009	0,009	0,011	0,006	0,009	0,010	0,007	0,009	0,013	0,006	0,009	0,011	0,008	0,009	0,011
exp_DG_oth	0,244*	0,213	0,200	0,243*	0,206	0,199	0,248*	0,208	0,200	0,235*	0,196	0,198	0,228*	0,192	0,190

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions. ** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale. *** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en Région Flamande.

Source : EBM 2002-2006. Calculs : BFP.

Pour revenir aux dépenses pour les biens liés aux transports, on constate une part des dépenses pour le diesel significativement plus importante en Wallonie et en Flandre (par rapport à Bruxelles-Capitale) dans chaque décile. La part des dépenses pour l'essence est également significativement plus importante dans les déciles Q1 à Q4 pour les ménages wallons et flamands et dans le décile Q9 pour les ménages résidant en Flandre. Les ménages bruxellois dans chaque décile se distinguent par une part de dépenses significativement plus élevée pour les transports en commun. Finalement, les ménages habitant en Flandre ont une part de dépense plus élevée pour le vélo dans les déciles Q2, Q3, Q4, Q5, Q8 et Q9. Pour les déciles Q1, Q6 et Q7, les parts des dépenses pour le vélo en Flandre ne sont pas significativement différentes de celles observées dans la Région de Bruxelles-Capitale.

En ce qui concerne les dépenses en énergie, les ménages bruxellois appartenant aux déciles Q1, Q2, Q5 et Q9 consacrent un part significativement plus importante de leur dépense totale pour le gaz. Une part des dépenses pour l'électricité significativement moins importante que celles observées en Flandre et en Wallonie est observée dans les déciles Q3, Q4, Q5 et Q7. Les ménages wallons dépensent davantage pour l'électricité (par rapport aux deux autres Régions) dans les déciles Q1, Q2, Q6, Q8 et Q9.

3.3. Revenus par type de ménages

Parallèlement à la section 3.2 consacrée à la part des dépenses pour chaque catégorie de bien dans les dépenses totales, cette section-ci présente la part des différentes catégories de revenus dans le revenu disponible pour les cinq classifications de ménages : déciles, Régions, niveaux d'instruction du chef de ménage, Régions par niveau d'instruction et Régions par décile du revenu disponible.

3.3.1. Déciles

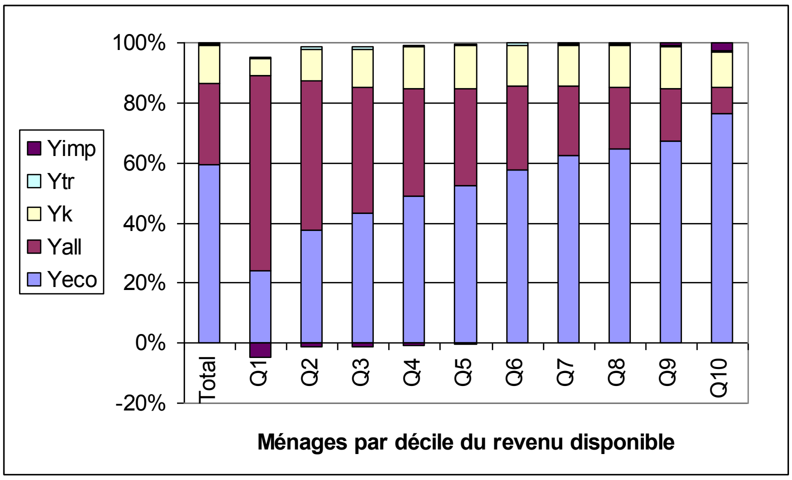
Sur base des chiffres présentés dans le Tableau 11, on constate sans surprise que la part des revenus provenant de l'activité économique augmente avec les déciles (26% pour les ménages appartenant au type Q1 et 76 % pour les ménages appartenant au type Q10). En parallèle, la part du revenu disponible des ménages relative aux allocations sociales diminue avec les déciles (71% pour les ménages appartenant au type Q1 et 8 % pour les ménages appartenant au type Q10). Les parts du revenu du patrimoine et des revenus transférés sont nettement moins dépendantes du type de ménages (basé sur les déciles dans le cas présent). En ce qui concerne la part des revenus liés aux charges relatives aux revenus, elle augmente légèrement avec les déciles. Ces résultats sont également présentés dans le Graphique 1.

Tableau 11 Parts des revenus des ménages dans le revenu disponible par décile (Σ par type de ménages = 1)

	Total	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Activité écono-mique (Yeco)	0,59	0,26	0,39	0,44	0,50	0,53	0,58	0,62	0,65	0,67	0,76
Patrimoine (Yk)	0,13	0,07	0,11	0,13	0,14	0,15	0,14	0,14	0,14	0,14	0,12
Allocations sociales (Yall)	0,27	0,71	0,51	0,43	0,36	0,32	0,28	0,23	0,21	0,17	0,08
Revenus transférés (Ytr)	0,002	0,005	0,009	0,010	0,007	0,004	0,005	0,004	0,003	0,006	0,004
Charges (Yimp)	0,01	-0,05	-0,01	-0,01	-0,01	0,00	0,00	0,00	0,01	0,01	0,03

Source : EBM 2002-2006.
Calculs : BFP.

Graphique 1 Parts des revenus des ménages par décile dans le revenu disponible du ménage



Source : EBM 2002-2006.
Calculs : BFP.

3.3.2. Régions

La répartition des différentes catégories de revenu dans le revenu disponible des ménages (Tableau 12 et Graphique 2) n'est pas très différente selon les Régions. On constate toutefois une différence significative entre la part des revenus liés à l'activité économique en Wallonie (56%) et celle observée en Flandre (60 %). De même, la part du revenu disponible relative au revenu du patrimoine est significativement plus élevée en Flandre (13.3%) qu'à Bruxelles-Capitale (12.1%)

Tableau 12 Parts des revenus des ménages par Région dans le revenu disponible en 2005 Régions (Σ par type de ménages = 1)

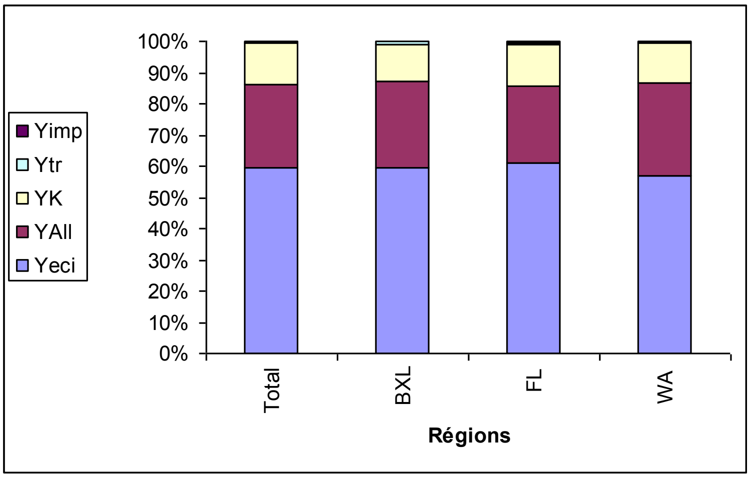
	Total	RBC	FL	WA
Activité économique (Yeco)	0,594	0,595	0,608	0,568***
Patrimoine (Yk)	0,130	0,121	0,133**	0,129
Allocations sociales (Yall)	0,266	0,276	0,250*	0,297
Revenus transférés (Ytr)	0,002	0,007	0,006	0,004
Charges (Yimp)	0,005	0,001	0,004	0,001

** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale. *** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en Région Flamande.

Source : EBM 2002-2006.

Calculs : BFP.

Graphique 2 Parts des revenus des ménages dans le revenu disponible par Région



Source : EBM 2002-2006.

Calculs : BFP.

3.3.3. Niveaux d'instruction du chef de ménage

A nouveau, la tendance générale observée dans l'analyse par décile se retrouve dans l'analyse par niveau d'instruction du chef de ménage (Tableau 13 et Graphique 3). La part des revenus de l'activité économique augmente de manière significative avec le niveau d'instruction (41% pour les ménages dont le chef de ménage a un niveau d'instruction inférieur au secondaire et 68 % pour les ménages dont le chef de ménage a un niveau d'instruction de type supérieur). La part des revenus provenant d'allocations sociales diminue également de manière significative avec le niveau d'instruction (de 44% pour un niveau d'instruction inférieur au secondaire à 19 % pour un niveau d'instruction de type supérieur). La part des revenus transférés est significativement plus faible pour les ménages dont le chef de famille a un niveau d'instruction de type supérieur. Quant à la part du revenu du patrimoine dans le revenu disponible des ménages, elle est significativement décroissante avec le niveau d'instruction (sous déclaration des revenus du patrimoine pour les revenus plus élevés ?). La part du revenu relative aux charges liées aux revenus est significativement plus importante pour les ménages dont le chef de ménage a un niveau d'instruction de type supérieur.

Tableau 13 Parts des revenus des ménages dans le revenu disponible par niveau d'instruction du chef de ménage (Σ par type de ménages = 1)

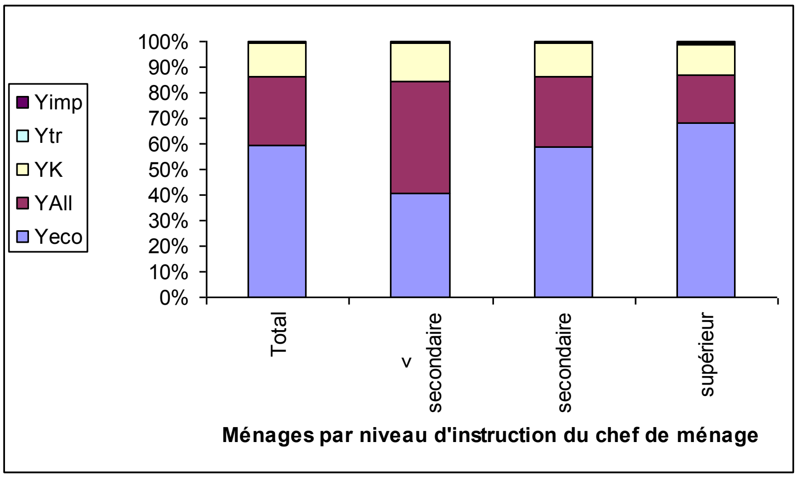
	Total	< secondaire	secondaire	supérieur
Activité économique (Yeco)	0,59	0,41*	0,59*	0,68*
Patrimoine (Yk)	0,13	0,15*	0,13*	0,12*
Allocations sociales (Yall)	0,27	0,44*	0,27*	0,19*
Revenus transférés (Ytr)	0,002	0,007	0,007	0,004*
Charges (Yimp)	0,01	-0,002	-0,0001	0,006*

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée pour les deux autres niveaux d'instruction.

Source : EBM 2002-2006.

Calculs : BFP.

Graphique 3 Part des revenus des ménages dans le revenu disponible par niveau d'instruction du chef de ménage



Source : EBM 2002-2006.

Calculs : BFP.

3.3.4. Régions par niveau d'instruction

Les parts des différentes catégories de revenus dans le revenu disponible des ménages par Région pour chaque niveau d'instruction du chef de ménage sont représentées dans le Tableau 14. Quelques résultats apparaissent statistiquement significatifs. Pour ce qui concerne les revenus de l'activité économique, la part est significativement plus petite dans la Région de Bruxelles-Capitale par rapport aux deux autres Régions, pour un niveau d'instruction du chef de ménage de type supérieur. Pour un niveau d'instruction de type supérieur, c'est la Wallonie qui se distingue par une part dans le revenu disponible plus petite. Pour le revenu du patrimoine, on observe une différence significative pour les ménages flamands dont le chef de famille a un niveau d'instruction inférieur au niveau secondaire. Finalement, la part des allocations sociales est plus faible en Flandre, pour les ménages dont le chef de famille a un niveau d'instruction secondaire ou inférieur au secondaire.

Tableau 14 Part des revenus des ménages par Région dans le revenu disponible et par niveau d'instruction du chef de ménage (Σ par type de ménages = 1)

	< secondaire			secondaire			supérieur		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
Activité économique	0,36	0,42	0,39	0,47*	0,61	0,57	0,69	0,68	0,66*
Patrimoine	0,12	0,16*	0,13	0,13	0,14	0,12	0,12	0,14	0,13
Allocations sociales	0,52	0,42*	0,47	0,38*	0,25*	0,30*	0,18	0,25	0,21
Revenus transférés	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,01	0,00
Charges	-0,01	-0,002	-0,002	-0,003	0,001	-0,002	0,004	0,001	0,005

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions.

Source : EBM 2002-2006

Calculs : BFP.

3.3.5. Régions par décile

Le Tableau 15 présente la part des différents revenus dans le revenu disponible des ménages par Région pour chaque décile. Sur base du test statistique basé sur la comparaison des intervalles de confiance, quelques parts des revenus par Région dans chaque décile apparaissent significativement différentes des autres Régions, mais cela reste marginal.

Tableau 15 Parts des revenus des ménages dans le revenu disponible par Région et par décile (Σ par type de ménages = 1)

		Q1			Q2			Q3			Q4			Q5	
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
Activité économique	0,25	0,32	0,22***	0,41	0,39	0,37	0,48	0,43	0,45	0,55	0,49	0,49	0,55	0,52	0,54
Patrimoine	0,02*	0,10*	0,06*	0,06*	0,12	0,10	0,11	0,14	0,13	0,10*	0,15	0,13	0,13	0,15	0,14
Allocations sociales	0,74	0,66	0,75	0,54	0,49*	0,53	0,42	0,43	0,42	0,35	0,36	0,39	0,32	0,32	0,32
Revenus transférés	0,01	0,00	0,01	0,01	0,01	0,01	0,00	0,01	0,01	0,01	0,01	0,00	0,00	0,00	0,01
Charges	-0,02	-0,08	-0,04***	-0,02	0.01	-0,01	-0,02	-0,01	-0,01	-0,01	-0,01	-0,01	0,00	0,00	0,00

		Q6			Q7			Q8			Q9			Q10	
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
Activité économique	0,62	0,58	0,56	0,62	0,62	0,63	0,65	0,66	0,63***	0,63	0,70	0,63***	0,74	0,77	0,76
Patrimoine	0,12	0,14	0,14	0,13	0,14	0,13	0,14	0,14	0,14	0,15	0,13	0,16***	0,15*	0,11	0,12
Allocations sociales	0,26	0,28	0,29	0,24	0,23	0,23	0,20	0,20	0,23	0,21	0,16	0,20***	0,09	0,08	0,09
Revenus transférés	0,01	0,01	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,01	0,01	0,00	0,01	0,00	0,00
Charges	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,01	0,00	0,01	0,01	0,01	0,02	0,03	0,03

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions. *** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en Région Flamande.

Source : EBM 2002-2006.

Calculs : BFP.:

3.4. L'épargne des ménages

L'épargne des ménages correspond à la différence entre le revenu disponible du ménage et les dépenses totales du même ménage. Les tableaux 16 à 20 présentent la part de l'épargne dans le revenu disponible des ménages pour chaque classification de ménage : déciles, Régions, niveaux d'instruction du chef de ménages, Régions par niveau d'instruction du chef de ménage et Régions par décile.

3.4.1. Déciles

Avec une moyenne au niveau national de 20.7%, le taux d'épargne passe de -19% pour les ménages du type Q1 à 45% pour les ménages appartenant au type Q10 (Tableau 16).

Tableau 16 Epargne des ménages par décile (% du revenu disponible)

	Total	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
% revenu disponible	20.7%	-19%	-1.8%	-3.6%	8.1%	12.7%	15.2%	20.5%	25.9%	31%	44.9%

Source : EBM 2002-2006
Calculs : BFP.

3.4.2. Régions

Le taux d'épargne des ménages n'est pas très différent entre les trois Régions du pays (Tableau 17). La Flandre a cependant un taux d'épargne significativement plus élevé que celui observé dans la Région de Bruxelles-Capitale.

Tableau 17 Epargne des ménages par Région (% du revenu disponible)

	Total	RBC	FL	WA
% revenu disponible	20.7%	17.6%	21.7%**	19.9%

** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale.
Source : EBM 2002-2006.
Calculs : BFP.

3.4.3. Niveaux d'instruction du chef de ménage

Les différences sur l'épargne des ménages sont davantage marquées lorsqu'on fait l'analyse par niveau d'instruction (Tableau 18) plutôt que par Région (Tableau 17). Les ménages dont le chef de ménage a un niveau d'instruction inférieur au niveau secondaire parviennent à épargner 15.3 % de leur revenu disponible, tandis que les ménages dont le chef de ménage a un niveau d'instruction secondaire épargnent 17.4 % et ceux dont le chef de ménage a un niveau d'instruction de type supérieur épargnent 24.8% de leur revenu disponible. Sur base des intervalles de confiance, seule la différence entre les ménages dont le chef de ménage a un niveau d'instruction inférieure au niveau supérieur et ceux dont le niveau d'instruction est de type supérieur est significativement différente.

Tableau 18 Epargne des ménages par niveau d'instruction du chef de ménage (% du revenu disponible)

	Total	< secondaire	secondaire	supérieur
% revenu disponible	20.7%	15.3%	17.4%	24.8%*

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions.

Source : EBM 2002-2006.

Calculs : BFP.

3.4.4. Régions par niveau d'instruction

Le Tableau 19 représente l'épargne des ménages par niveau d'instruction et par région. Deux résultats apparaissent statistiquement significatifs. Premièrement, pour les ménages dont le chef de famille a un niveau d'instruction secondaire, l'épargne est plus faible dans la Région de Bruxelles-Capitale. Deuxièmement, pour les ménages dont le chef de famille a un niveau d'instruction supérieur, la part de l'épargne est plus importante en Flandre.

Tableau 19 Epargne des ménages par niveau d'instruction du chef de ménage et par Région (% du revenu disponible)

	< secondaire			secondaire			supérieur		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
% revenu disponible	11.8%	15.6%	15.6%	9.4%*	18.4%	17.1%	21.5%	26.1%**	23.6%

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions.

** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en dans la Région de Bruxelles-Capitale.

Source : EBM 2002-2006.

Calculs : BFP.

3.4.5. Régions par décile

L'épargne des ménages par Région pour chaque décile du revenu disponible est présentée dans le Tableau 20. Les différences régionales apparaissent statistiquement significatives principalement dans les déciles extrêmes (Q1, Q2, Q3, Q4, Q9). Alors que l'épargne apparaît plus élevée en Flandre dans le décile Q9, c'est la Wallonie qui semble avoir un taux d'épargne plus élevé (ou moins négatif !) dans les déciles Q1, Q2, Q3 et Q4.

Tableau 20 **Epargne des ménages par décile et par Région (% du revenu disponible)**

	Q1			Q2			Q3			Q4			Q5		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
% revenu disponible	-14%*	-29%*	-12%*	-10%	-3%	2%*	-6%*	4%	5%	-1%*	9%	9%	5%	14%	13%
	Q6			Q7			Q8			Q9			Q10		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
% revenu disponible	9%	17%	14%	17%	20%	20%	23%	26%	26%	26%	32%**	30%	45%	45%	46%

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions. ** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale.

Source : EBM 2002-2006

Calculs : BFP.

4. Analyse de la distribution des revenus

Dans le cadre d'un modèle d'équilibre général, il est pertinent d'étudier l'impact de différents scénarios sur la distribution des revenus par types de ménages. Cette section présente une analyse de la distribution des revenus pour chaque classification des ménages pour une situation de référence. L'objectif étant de comparer, dans une étape ultérieure, les distributions des revenus obtenus suite à l'intégration de différents scénarios dans le modèle d'équilibre général construit dans le cadre du projet LIMOBEL.

L'analyse de la distribution des revenus se fait sur base du revenu disponible équivalent (échelle modifiée de l'OCDE). De même, l'analyse est réalisée au niveau des ménages, et pas au niveau des individus. Ce qui empêche de comparer les résultats (cœfficient de GINI, taux de pauvreté…) avec, notamment, les résultats de l'enquête EU-SILC[1]. Etant donné que l'objectif de l'étude se concentre sur le comportement des ménages, il semble cependant plus approprié de continuer l'analyse au niveau des ménages[2]. De plus, dans le cadre d'un modèle d'équilibre général, ce ne sont pas tellement les valeurs qui sont analysées mais plutôt les tendances observées entre la situation de départ au temps t, et la période t +x.

Dans la section 3 toutes les données disponibles ont été regroupées sans tenir compte de l'année, ce qui a permis d'obtenir un plus grand nombre d'observations et des résultats plus robustes. De plus, la classification de ménages par type ne dépend pas de l'année. Dans le cadre de l'analyse de la distribution des revenus, il semble préférable de faire l'analyse par année. Cette note présente les résultats pour l'année 2005. Le modèle d'équilibre général développé dans le cadre du projet LIMOBEL sera en effet calibré sur des données de 2005 (les parts de dépenses et des revenus par type de ménages seront donc également calculées pour cette année là). Afin d'avoir une vue plus globale de quelques indicateurs de pauvreté et d'inégalité, un tableau synthétique pour les années 2002 à 2006 est également présenté à la fin de cette section. Ce qui permet également de tester la fiabilité des données par année.

4.1. Distribution des revenus équivalents par type de ménages

La première partie de cette section est consacrée à une analyse descriptive de la distribution du revenu disponible équivalent pour les différentes classifications de ménages étudiées dans les sections précédentes : déciles, Régions, niveaux d'instruction du chef de ménage, Régions par niveau d'instruction et déciles par niveau d'instruction. En plus des statistiques classiques d'une distribution (moyenne, médiane, minimum, maximum), les tableaux intègrent la part de la population pour chaque type de ménages, la part dans le revenu total de la population, ainsi

[1] Statistics on Income and Living Conditions.

[2] L'enquête budget des ménages attribue le même coefficient d'extrapolation au ménage et aux membres du ménage. L'analyse de la distribution des revenus au niveau des individus peut donc techniquement se faire en multipliant le coefficient d'extrapolation du ménage par le nombre de personnes dans le ménage.

que le taux de pauvreté, à savoir le pourcentage de ménages en dessous du seuil de pauvreté. Le seuil de pauvreté est défini comme étant égal à 60% de la médiane du revenu disponible équivalent.

4.1.1. Déciles

Dans le cas d'une classification des ménages par décile du revenu disponible (Tableau 21), il est tout à fait logique d'obtenir des moyennes, médianes, minima et maxima qui augmentent avec les déciles. De même, la part des ménages dans chaque type de ménages est égale à 10%. La part dans le revenu total de la population suit également une tendance logique : la part augmente avec les déciles (de 3.9% pour les ménages appartenant au premier décile – Q1- à 20.2%pour les ménages appartenant au dernier décile – Q10). Finalement, le pourcentage de ménages en dessous du seuil de pauvreté est différent de zéro seulement pour les ménages appartenant au type Q1 (100% < seuil de pauvreté) et au type Q2 (36% < seuil de pauvreté).

Tableau 21 Distribution du revenu disponible équivalent (EUR/an) par décile : statistiques

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total
Revenu moyen	9856	13869	16492	18947	21264	23603	26440	30213	35574	49738	24605
Revenu médian	10365	13844	16517	18958	21335	13471	26358	30120	35520	45770	22455
Revenu minimal	1800	12432	15262	17727	20096	22456	24910	28140	32585	39301	1800
Revenu maximal	12425	15256	17723	20089	22449	21904	28119	32571	39249	118947	118947
Part de la population	10	10	10	10	10	10	10	10	10	10	100%
Part dans le revenu total de la population	3.9	5.6	6.6	7.7	8.6	9.5	10.7	12.2	14.4	20.2	100%
% < seuil de pauvreté	100	36.7	0	0	0	0	0	0	0	0	13.6%

Source : EBM 2005.
Calculs : BFP.

4.1.2. Régions

Sur base de l'analyse par Région (Tableau 22) on constate un revenu moyen plus élevé en Flandre (25 621 EUR/an) puis à Bruxelles (23 422 EUR/an) et ensuite en Wallonie (23 197 EUR/an). Le revenu médian est cependant plus élevé en Wallonie qu'à Bruxelles. Les chiffres indiquent également que les ménages habitant en Flandre contribuent plus que proportionnellement au revenu total de la population. La Belgique compte en effet 56.3% de ménages flamands et le revenu total de la population comprend 58.7% des revenus provenant de ces mêmes ménages. A l'inverse, la région de Bruxelles-Capitale et la Wallonie contribuent moins que proportionnellement au revenu total disponible en Belgique. Enfin, Bruxelles se caractérise par un taux de pauvreté plus important (25.6%) qu'en Flandre (9.8%) ou en Wallonie (16.3%).

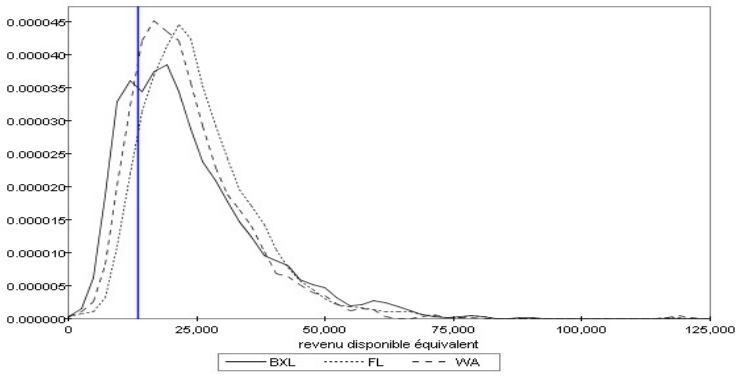
Tableau 22 Distribution du revenu disponible équivalent (EUR/an) par Région : statistiques

	RBC	FL	WA	Total
Revenu moyen (EUR/an)	23422	25651	23197	24605
Revenu médian (EUR/an)	20444	23381	20973	22455
Revenu minimal (EUR/an)	3409	1800	2089	1800
Revenu maximal (EUR/an)	88733	118083	118947	118947
Part de la population (%)	10.8	56.3	32.7	100
Part dans le revenu total de la population (%)	10.3	58.7	30.9	100
% < seuil de pauvreté	25.6	9.8	16.3	13.6

Source : EBM 2005.
Calculs : BFP.

Le taux de pauvreté plus élevé dans la région de Bruxelles-Capitale peut se voir graphiquement (Graphique 4) par l'aire à gauche du seuil de pauvreté qui est plus importante pour la Région bruxelloise que pour la Flandre et la Wallonie. On remarque également que la distribution des revenus des ménages Bruxellois a une plus grande dispersion (plus grande variance).

Graphique 4 Distribution du revenu disponible annuel (EUR/an) des ménages par région



Source : EBM 2005.
Calculs : BFP.

4.1.3. Niveaux d'instruction du chef de ménage

Le revenu moyen et le revenu médian sont positivement corrélés au niveau d'instruction du chef de ménage (Tableau 23). De même, la part dans le revenu total de la population est plus (resp. moins) que proportionnelle à la part de ménages dans la population pour les ménages dont le chef de famille a un niveau d'instruction de type supérieur (resp. secondaire ou inférieur au secondaire). Le taux de pauvreté est négativement corrélé au niveau d'instruction du chef de ménage (23.8% pour les ménages dont le chef de famille a un niveau d'instruction inférieur au secondaire et 6.2% pour les ménages dont le chef de famille a un niveau d'instruction de type supérieur).

Tableau 23 Distribution du revenu disponible équivalent (EUR/an) par niveau d'instruction du chef de ménage: statistiques

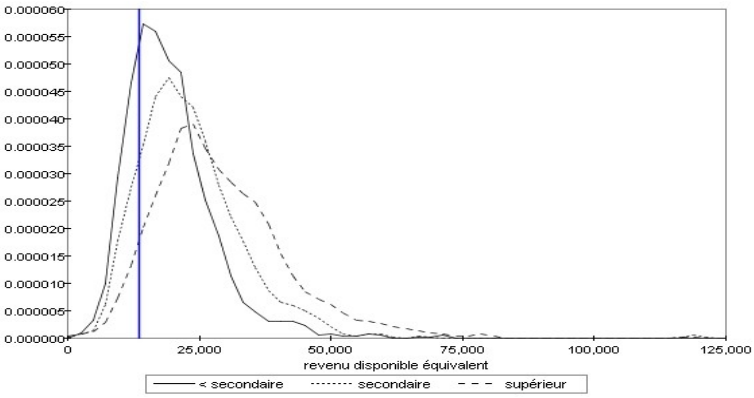
	< secondaire	secondaire	supérieur	Total
Revenu moyen (EUR/an)	19520	23347	29065	24605
Revenu médian (EUR/an)	18085	21752	26840	22455
Revenu minimal (EUR/an)	2171	1905	1800	1800
Revenu maximal (EUR/an)	83313	118947	118083	118947
Part de la population (%)	30.0	27.9	42.1	100
Part dans le revenu total de la population (%)	23.8	26.4	49.7	100
% < seuil de pauvreté	23.8	14.0	6.2	13.6

Source : EBM 2005

Calculs : BFP.

Sur base du Graphique 5 représentant la distribution du revenu disponible équivalent (EUR/an) des ménages par niveau d'instruction du chef de famille, on constate que la distribution composée par les chefs de ménage possédant un niveau d'instruction de type supérieur est plus plate que celles pour un niveau d'instruction secondaire ou inférieur au secondaire. L'aire à gauche du seuil de pauvreté (représenté par la ligne verticale) représentant le taux de pauvreté est également décroissante avec le niveau d'instruction.

Graphique 5 Distribution du revenu disponible équivalent (EUR/an), par niveau d'instruction du chef de ménage.



Source : EBM 2005.

Calculs : BFP.

4.1.4. Régions par niveau d'instruction

Quel que soit le niveau d'instruction du chef de ménage, on observe toujours une moyenne et une médiane du revenu disponible plus élevées en Flandre qu'à Bruxelles ou en Wallonie (Tableau 24). De même, le seuil de pauvreté est plus élevé à Bruxelles, suivi de la Wallonie et ensuite de la Flandre, pour chaque niveau d'instruction du chef de ménage.

Tableau 24 Distribution du revenu disponible équivalent par niveau d'instruction du chef de ménage et par Région : statistiques

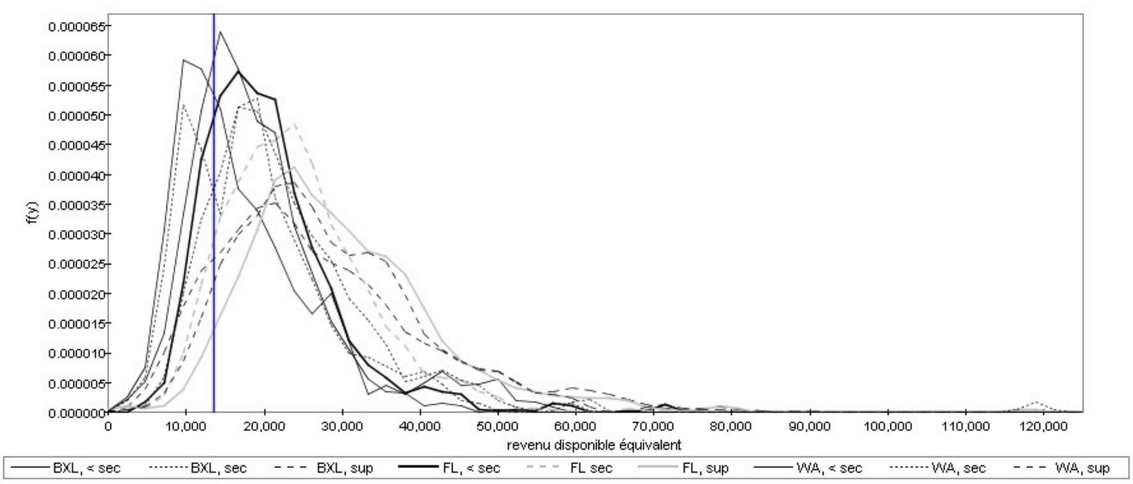
	moyenne (EUR/an)	médiane (EUR/an)	minimum (EUR/an)	maximum (EUR/an)	Part de la population	Part dans le revenu total de la population	% < seuil de pauvreté.
< sec, RBC	18632	15172	3409	55344	2,1	1,6	43.17
< sec, FL	20633	19196	5287	83813	16,2	13,6	18.74
< sec, WA	18125	17103	2171	50819	11,6	8,5	27.46
sec, RBC	19180	17642	3750	60929	2,9	2,3	32.78
sec, FL	24233	23165	1905	72345	16,1	15,9	9.78
sec, WA	23137	20416	3225	118947	8,7	8,2	15.36
sup, RBC	27457	23971	5658	88733	5,6	6,3	15.28
sup, FL	30009	27664	1800	118083	23,9	29,2	3.85
sup, WA	27979	25899	2089	78557	12,4	14,1	6.60

Source : EBM 2005

Calculs : BFP

Etant donné le nombre de types de ménage (9), la lecture du Graphique 6 représentant la distribution du revenu disponible par Région pour chaque niveau d'instruction du chef de ménage devient plus difficile. On observe toujours une distribution des revenus disponibles plus plate dans chaque Région pour les ménages dont le chef de famille a un niveau d'instruction de type supérieur. On observe aussi que la distribution du revenu disponible pour les ménages bruxellois dont le chef de famille a un niveau d'instruction inférieur au niveau secondaire présente la plus grande aire à gauche du seuil de pauvreté (taux de pauvreté = 43% - Tableau 24).

Graphique 6 Distribution du revenu disponible annuel des ménages (EUR/an), par niveau d'instruction du chef de ménage et par région



Source : EBM 2005

Calculs : BFP

4.1.5. Régions par décile

Le Tableau 25 présente les statistiques de la distribution du revenu disponible équivalent par région, pour chaque décile. Par décile, les moyennes et les médianes pour chaque Région ne semblent pas différentes.

Tableau 25 Distribution du revenu disponible équivalent par décile du revenu disponible et par Région : statistiques

	moyenne (EUR/an)	médiane (EUR/an)	minimum (EUR/an)	maximum (EUR/an)	Part de la population	Part dans le revenu total de la population	% < seuil de pauvre-té.
Q1, RBC	9598	9719	3409	12425	2,25	0,8	100
Q1, FL	10016	10644	1800	12406	3,65	1,48	100
Q1, WA	9856	10441	2089	12425	4,06	1,62	100
Q2, RBC	13730	13435	12448	15256	0,95	0,5	54.37
Q2, FL	13843	13843	12442	15189	5,13	2,88	37.00
Q2, WA	13937	13896	12432	15240	3,92	2,22	32.77
Q3, RBC	16618	16689	15333	17723	1,05	0,7	0
Q3, FL	16496	16535	15284	17715	5,14	3,45	0
Q3, WA	16453	16440	15262	17690	3,78	2,53	0
Q4, RBC	18794	18671	17791	20089	1,01	0,7	0
Q4, FL	18960	18988	17750	20086	5,62	4,33	0
Q4, WA	18972	18978	17727	20079	3,36	2,59	0
Q5, RBC	21076	20989	20122	22414	0,85	0,7	0
Q5, FL	21308	21355	20096	22449	5,9	5,11	0
Q5, WA	21233	21350	20100	22420	3,24	2,8	0
Q6, RBC	23545	23512	22487	24772	0,85	0,8	0
Q6, FL	23642	23504	22456	24904	6,18	5,94	0
Q6, WA	23539	23368	22514	24835	2,93	2,8	0
Q7, RBC	26490	26329	24916	28119	0,75	0,8	0
Q7, FL	26433	26345	24932	28104	6,16	6,62	0
Q7, WA	26441	26396	24910	28066	3,08	3,31	0
Q8, RBC	30067	30004	28168	32497	0,89	1,08	0
Q8, FL	30184	30074	28177	32571	6,25	7,67	0
Q8, WA	30321	30432	28140	32457	2,86	3,53	0
Q9, RBC	35390	35234	32599	39180	0,87	1,25	0
Q9, FL	35588	35652	32585	39249	6,26	9,05	0
Q9, WA	35602	35448	32596	39139	2,87	4,15	0
Q10, RBC	50379	47092	39705	88733	1,31	2,69	0
Q10, FL	49661	45286	39301	118083	6,04	12,2	0
Q10, WA	49595	45874	39427	118947	2,63	5,31	0

Source : EBM 2005.

Calculs : BFP

4.2. Mesures de pauvreté

Cette section présente, pour l'année 2005, le seuil de pauvreté, le taux de pauvreté, ainsi que l'indicateur FGT (Foster, Greer et Thorbecke) pour les différentes classifications de ménages. L'indicateur FGT permet de décomposer le taux de pauvreté par type de ménages. Il est ainsi possible de déterminer quel(s) type(s) de ménages influence(nt) davantage le taux de pauvreté total (national).

a. Seuil de pauvreté

Pour l'année 2005, le seuil de pauvreté (60% de la médiane du revenu disponible) est fixé à 13 473 EUR par an pour un ménage isolé (1 122 EUR par mois). Pour un couple avec deux enfants, le seuil de pauvreté revient à 30 982 EUR par an (2 582 EUR par mois). Le seuil de pauvreté sert de référence pour calculer le taux de pauvreté.

b. Le taux de pauvreté

Le taux de pauvreté au niveau national était, en 2005, de 13.6 %. Ce qui revient à dire que 1 ménage sur 7 vivait sous le seuil de pauvreté.

c. L'indicateur FGT (Foster, Greer et Thorbecke)

L'indicateur FGT permet de décomposer le taux de pauvreté en fonction de différents types de ménages. Il met en évidence la contribution de ces différents types dans le taux de pauvreté total.

Le Tableau 26 présente les résultats de la décomposition du taux de pauvreté par décile. On constate que seuls les ménages appartenant aux deux premiers déciles du revenu disponible contribuent au taux de pauvreté national (13.6%). Les ménages du premier décile contribuent pour 73% au taux de pauvreté alors que les ménages du deuxième décile y contribuent pour 27%.

Tableau 26 Pauvreté : indicateur FGT (α=0), décomposition par décile

	Taux de pauvreté (%)	Part de la population (%)	contribution absolue (%)	contribution relative (%)
Q1	100	10	10	72.93
Q2	36.70	10	3.70	27.07
Q3-Q10	0	80	0	0
Total		100	13.6	100%

Source : EBM 2005.
Calculs : BFP.

La décomposition du taux de pauvreté par Région est présentée au Tableau 27. Malgré un taux de pauvreté relativement élevé à Bruxelles (25.6%) par rapport à la Flandre (9.8%) et à la Wallonie (16.3%), on constate que la contribution relative de la Région bruxelloise (20%) au taux de pauvreté national est moins importante que celle de la Wallonie (39%) ou de la Flandre (41%).

Tableau 27 Pauvreté : indicateur FGT(α=0), décomposition par région

	Taux de pauvreté (%)	Part de la population (%)	contribution absolue (%)	contribution relative (%)
RBC	25.6	10.8	2.77	20.29
FL	9.8	56.4	5.55	40.57
WA	16.3	32.8	5.35	39.12
Total		100	13.6	100

Source : EBM 2005.

Calculs : BFP.

En ce qui concerne la décomposition du taux de pauvreté par niveau d'instruction du chef de ménage (Tableau 28), on constate que le taux national est majoritairement composé de ménages dont le chef de famille a un niveau d'instruction inférieur au niveau secondaire, alors que ce type de ménages représente un tiers des ménages belges.

Tableau 28 Pauvreté : indicateur FGT(α=0), décomposition par niveau d'instruction du chef de ménage

	Taux de pauvreté (%)	Part de la population (%)	contribution absolue (%)	contribution relative (%)
< secondaire	23.8	30.0	7.15	52.32
secondaire	14.0	27.9	3.9	28.57
supérieur	6.2	42.1	2.61	19.09
Total		100	13.15	100

Source : EBM 2005.

Calculs : BFP.

A la lecture du Tableau 29, les types de ménages qui contribuent majoritairement au taux de pauvreté national (plus de 60%) sont ceux dont le chef de famille a un niveau d'instruction inférieur à un niveau d'instruction de type supérieur et qui habitent en Flandre ou en Wallonie.

Tableau 29 Pauvreté : indicateur FGT (α=0), décomposition par Région et par niveau d'instruction

	Taux de pauvreté (%)	Part de la population (%)	contribution absolue (%)	contribution relative (%)
< sec, RBC	43,1	2,1	0,9	6,7
< sec, FL	18,7	16,25	3,04	22,2
< sec, WA	27,4	11,6	3,18	23,29
sec, RBC	32,7	2,99	0,9	7,1
sec, FL	9,7	16,1	1,58	11,56
sec, WA	15,36	8,75	1,34	9,83
sup, RBC	15,28	5,69	0,87	6,3
sup, FL	3,85	23,97	9,23	6,74
sup, WA	6,6	12,41	0,81	5,9

Source : EBM 2005.
Calculs : BFP.

Finalement, le tableau 30 présente la décomposition du taux de pauvreté par Région et par décile. 6 types de ménages sur 30 contribuent au taux de pauvreté, à savoir les ménages appartenant aux déciles Q1 et Q2. Les ménages wallons et flamands appartenant au décile Q1 contribuent pour plus de 55% au taux de pauvreté national.

Tableau 30 Pauvreté : indicateur FGT(α=0), Régions par décile, 2005

	Taux de pauvreté (%)	Part de la population (%)	contribution absolue (%)	contribution relative (%)
Q1, RBC	100	2.25	2.25	16.5
Q1, FL	100	3.65	3.65	26.6
Q1, WA	100	4.06	4.06	29.73
Q2, RBC	54.37	0.95	0.51	3.7
Q2, FL	37	5.13	1.90	13.88
Q2, WA	32.77	3.92	1.28	9.39
Q3 – Q10	0	80	0	0
Total		100%	13,6%	100%

Source : EBM 2005.
Calculs : BFP.

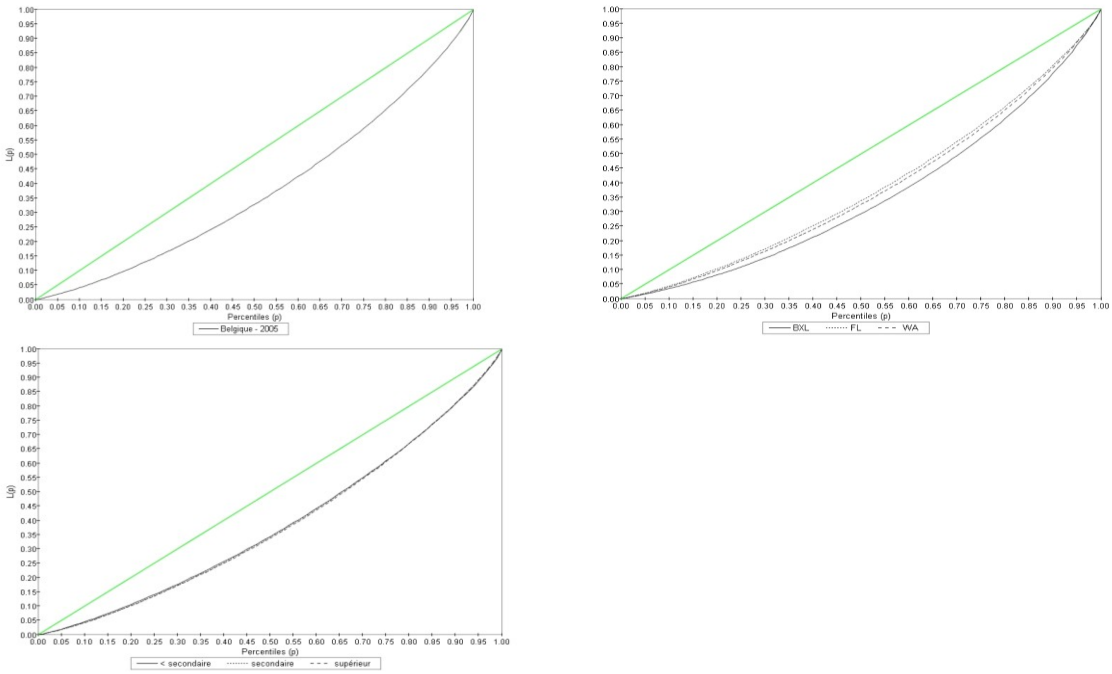
4.3. Mesures d'inégalité

a. Courbe de Lorenz

La courbe de Lorenz est une représentation graphique des inégalités de revenu au sein d'une population. La part cumulée de la population est représentée (par ordre croissant des revenus des ménages) en abscisse et la part cumulée des revenus en ordonnée. La droite à 45° représente donc une situation d'égalité parfaite, à savoir que tous les ménages reçoivent le même revenu.

Le Graphique 7 représente les courbes de Lorenz pour les ménages belges sans distinction, par Région et par niveau d'instruction du chef de ménage. Les courbes de Lorenz par Région confirment les résultats du Tableau 22 et du Graphique 4. La distribution des revenus est en effet plus inégale à Bruxelles (plus de ménages aux extrémités de la distribution), ce qui se traduit par une courbe de Lorenz pour la Région de Bruxelles-Capitale plus éloignée de la droite à 45°. Les courbes de Lorenz par niveau d'instruction du chef de ménage ne paraissent pas différentes l'une de l'autre.

Graphique 7 Courbes de Lorenz –Belgique, Régions, niveaux d'instruction



Source : EBM 2005

Calculs : BFP.

b. Coefficient de Gini

Le coefficient de GINI, pour l'année 2005 – en Belgique - , est de 25.0. Il représente la surface entre la droite à 45 degré et la courbe de Lorenz. Plus la valeur tend vers 0, plus les revenus sont distribués équitablement. Inversement, plus la valeur du coefficient de GINI tend vers 100, plus les revenus sont distribués inéquitablement.

4.4. Tendances

Afin d'observer les tendances et de tester la fiabilité de la base de données par année, 4 indicateurs de pauvreté et d'inégalité ont été calculés (sans distinction du type de ménages) pour les années 2002 à 2006 séparément : coefficient de Gini, seuil de pauvreté, taux de pauvreté et le ratio des quintiles (Q20/Q80)[3]. Afin de pouvoir comparer les résultats avec ceux publiés sur base de l'enquête EU-SILC, l'analyse est réalisée au niveau des individus, et plus des ménages (comme dans les sections 4.1, 4.2 et 4.3). La différence se fait au niveau des coefficients d'extrapolation. Pour faire l'analyse au niveau des individus, les coefficients d'extrapolations sont multipliés par le nombre d'individus dans le ménage[4]. Les résultats sont synthétisés dans le Tableau 31 et par le Graphique 8.

[3] Ratio de la moyenne des revenus des ménages inférieurs au quintile 0.2 et de la moyenne des revenus des ménages supérieurs au quintile 0.8.

[4] Les coefficients d'extrapolation correspondent à des fréquences, et non des probabilités.

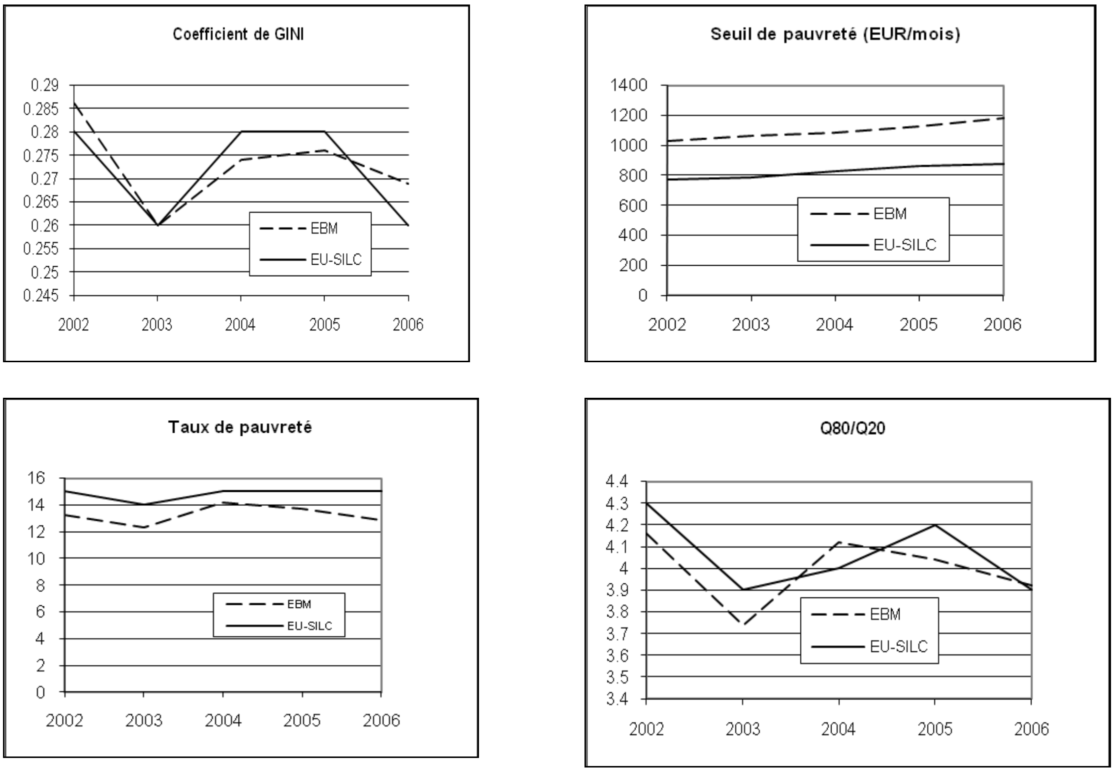
Tableau 31 Indicateurs de pauvreté et d'inégalité : Tendance de 2002 à 2006

	EBM				EU-SILC			
	Gini	seuil de pauvreté (EUR/mois)	Taux de pauvreté	q20/q80	Gini	seuil de pauvreté (EUR/mois)	Taux de pauvreté	q20/q80
2002	0,286	1028	13,22	4,16	0,28	772,56	15,2	4,3
2003	0,26	1067	12,35	3,74	0,26	777	14,8	4
2004	0,274	1086	14,17	4,12	0,28	822	14,7	4,1
2005	0,276	1129	13,7	4,04	0,27	860	14,7	4,2
2006	0,269	1179	12,9	3,92				

Sources : SILC : DGSIE.
EBM : calcul BFP.

Les résultats montrent une tendance relativement similaire entre les données de l'enquête EU-SILC et les données de l'enquête sur le budget des ménages. Les différences de niveau s'expliquent par la différence au niveau de la procédure d'échantillonnage (notamment la taille de l'échantillon), ainsi que par les composants inclus dans la définition du revenu disponible (p.ex. : l'enquête budget des ménages intègre le revenu fictif du logement –estimé par la DGSIE[5]- , alors que l'enquête SILC ne l'intègre pas[6]).

Graphique 8 Evolution des indicateurs de pauvreté et d'inégalité



Sources : SILC : DGSIE.
EBM : calcul BFP.

[5] La méthode d'estimation est modifiée à partir 2005.
[6] Le revenu fictif du logement sera pris en compte à partir de 2007 dans l'enquête EU-SILC.

5. Quel(s) critère(s) pour définir les types de ménages ?

L'analyse descriptive des parts des dépenses pour les biens de consommation et des parts des différentes catégories de revenu dans le revenu disponible, ainsi que l'analyse de la distribution des revenus ont été réalisées sur base de 5 classifications des ménages : les déciles, les Régions, les niveaux d'instruction du chef de ménage, les Régions par niveau d'instruction et les Régions par décile. Si on souhaite intégrer différents types de ménages dans un modèle d'équilibre général, il est nécessaire de faire un choix sur la classification des ménages qui sera utilisée. Ce choix doit tenir compte des deux objectifs mentionnés au début de cette note. Premièrement, la classification doit regrouper au mieux des ménages ayant des comportements semblables en matière de consommation de biens et de services (objectif de modélisation du comportement des ménages dans un modèle d'équilibre général). Deuxièmement, la classification doit également permettre une analyse pertinente de la distribution des revenus des ménages (objectif d'analyse de la distribution des revenus).

La classification par décile (10 types de ménages) est souvent utilisée car il s'agit d'une classification assez générale et qui ne requiert pas d'autre information que le revenu pour construire les types de ménages. Cependant, l'analyse de la distribution des revenus, en décomposant le taux de pauvreté par décile, semble moins pertinente dans le sens où on sait d'avance que le taux de pauvreté se compose des déciles les plus petits. De plus, du point de vue des comportements de consommation, on peut penser qu'une classification par décile ne regroupe pas les ménages de manière homogène. Les ménages appartenant à un même décile peuvent présenter des caractéristiques socio-économiques et démographiques très différentes. De ce fait, si on souhaite mettre en œuvre/simuler une politique efficace axée sur certains types de ménages (ex : ceux qui contribuent le plus au taux de pauvreté, ceux qui consomment davantage un bien x…), il devient difficile de cibler et d'intervenir sur ces ménages.

Dans une optique régionale, les statistiques des dépenses et des revenus ont été réalisées par Région pour chaque décile afin de tester si les ménages appartenant à un même décile adoptent des comportements différents (en termes de dépenses). Cette hypothèse semble se confirmer pour certains types de biens. Le passage de 10 types de ménages à 30 types de ménages (3 Régions * 10 déciles) pose cependant un problème au niveau du nombre d'observations par type de biens et services. Pour certaines cellules (types de ménages * types de biens) on n'observe d'ailleurs aucune dépense. Cet élément doit également être pris en compte lorsqu'on définit les types de ménages. Bien que les résultats montrent des différences significatives, étant donné les désavantages d'une classification par décile (paragraphe précédent) et le problème du nombre d'observations par cellule, une classification des ménages par Région et par décile du revenu disponible ne parait pas être la plus pertinente.

Reste alors les classifications des ménages sur base de variables socio-économiques et démographiques. Une classification basée sur le niveau d'instruction semble intéressante dans la mesure où la corrélation entre le revenu et le niveau d'instruction est relativement élevée. Ce qui permet de garder une classification fort générale (semblable au décile) tout en permettant de mieux cibler les ménages pour mettre en place/simuler une politique. Une classification par niveau d'instruction permet en effet de regrouper des ménages plus homogènes. L'analyse de la distribution des revenus par niveau d'instruction semble plus pertinente et on augmente le nombre d'observations par type de ménages. Dans une optique régionale, on peut même coupler le niveau d'instruction et la Région (9 types de ménages). Les résultats de l'analyse statistique des parts des dépenses pour cette classification des ménages sont en effet significatifs. Il s'agit alors d'un bon compromis entre une désagrégation des types de ménages, un nombre pas trop élevé de types de ménages, et une certaine homogénéité des ménages appartenant à un même type. Comme argument supplémentaire, on peut également mentionner que le niveau d'instruction est plus stable dans le temps que le revenu disponible des ménages. Les revenus et les dépenses dans l'enquête budget des ménages correspondent aux revenus encaissés durant le mois de l'enquête et aux dépenses réalisées pendant ce mois. Pour diverses raisons, ces montants peuvent varier d'un mois à l'autre (on risque par exemple de classer un ménage dans un décile trop bas car, ce mois là, un des membres n'a pas travaillé pendant 15 jours). Le niveau d'instruction du chef de ménage n'évolue par contre pas d'un mois à l'autre. Une classification basée sur le niveau d'instruction du chef de ménage peut cependant paraître *politiquement incorrect*, dans le sens où il pourrait s'avérer délicat de définir des politiques sur base du niveau d'instruction d'un individu. Le statut socio-économique du chef de ménage (actif occupé, actif sans emploi, pensionné) pourrait dans cette optique s'avère être un critère plus neutre et plus facilement détectable (sur base des différents registres). Les parts des dépenses et des revenus sont présentées dans les tableaux A.1 et A.2.

Si on sait quel(s) type(s) de politique(s) on souhaite mettre en œuvre (dans un domaine bien précis) on peut également penser à d'autres classifications. Par exemple, si on souhaite modifier le comportement des ménages en matière de mobilité, il semble important de définir les types de ménages en fonction de critères socio-économiques et démographiques qui définissent le comportement des ménages en terme de mobilité. Dans cette optique, une analyse en composante principale a été réalisée pour définir des types de ménages représentatifs au niveau de l'utilisation des différents modes de transport (les détails de l'analyse sont disponibles auprès de l'auteur). Par représentativité, on entend que les ménages appartenant à un même groupe adoptent des comportements similaires en termes d'utilisation des différents modes de transport existants. Par opposition, les ménages qui n'appartiennent pas à un même groupe adoptent des comportements différents. 10 types de ménages ont pu être identifiés (Tableau 32). Les parts des dépenses et des revenus sont représentées dans les tableaux A.3 et A.4.

Tableau 32 : Classification des ménages sur base des dépenses de transport

Libellé	Caractéristiques des ménages
T1	Bruxelles, actif[1]
T2	Bruxelles, inactif[1]
T3	Flandres, actif, accès faible au transport en commun
T4	Flandres, actif, accès facile ou moyen au transport en commun
T5	Flandres, inactif, accès faible au transport en commun
T6	Flandres, inactif, accès facile ou moyen au transport en commun
T7	Wallonie, actif, accès faible au transport en commun
T8	Wallonie, actif, accès facile ou moyen au transport en commun
T9	Wallonie, inactif, accès faible au transport en commun
T10	Wallonie, inactif, accès facile ou moyen au transport en commun

[1] : statut socioprofessionnel du chef de ménage

6. Annexe

Tableau A.1 Part des dépenses dans les dépenses totales par Région et par statut socioprofessionnel du chef de ménage (Σ par type de ménages = 1)

	inactif			actif sans emploi			actif occupé		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
exp_carE	0,046	0,064	0,069	0,018	0,046	0,062*	0,096	0,099	0,100
exp_carT	0,005	0,010**	0,008	0,003	0,006	0,008**	0,005*	0,008	0,007
exp_motoE	0,001	0,001	0,001	0,000	0,000	0,001	0,005	0,004	0,003
exp_motoT	0	0,0000	0,00001	0	0,00011	0	0,00003	0,00008	0,00005
exp_gaso	0,009*	0,014	0,013	0,008*	0,015	0,014	0,010*	0,013	0,013
exp_dies	0,003*	0,010	0,009	0,005*	0,010	0,013	0,008*	0,016*	0,021*
exp_lpg	0,0001	0,0002	0,0004**	0,0001*	0,0011	0,0007	0,0001*	0,0006	0,0008
exp_oil	0,00000*	0,0001	0,0002	0	0,0002	0,0001	0,0000*	0,0002	0,0001
exp_rail	0,002*	0,001	0,001	0,004	0,003	0,003	0,003	0,003	0,003
exp_BTM	0,003*	0,001	0,001	0,008*	0,002	0,004	0,005*	0,001*	0,002*
exp_FoBi	0,001	0,002*	0,000	0,001	0,003	0,000	0,001	0,004	0,001***
exp_oth_tr	0,002	0,002	0,001	0,003	0,001	0,001	0,007*	0,002	0,001
exp_gaz	0,023*	0,018	0,017	0,029	0,024	0,022*	0,019	0,016*	0,012*
exp_elec	0,020*	0,024*	0,028*	0,027	0,027	0,035*	0,017*	0,021*	0,024*
exp_ene_S	0,000*	0,001	0,001	0,000418	0,00051	0,002	0,000	0,000	0,001*
exp_ene_L	0,004*	0,014*	0,023*	0,005	0,005	0,019*	0,003	0,006*	0,016*
exp_ene_oth	0,003	0,001	0,001	0,006	0,001	0,002	0,002	0,001	0,001
exp_health	0,063	0,062	0,067	0,043	0,042	0,038	0,042	0,037*	0,041
exp_text	0,027	0,035*	0,029	0,036	0,036	0,032	0,051	0,057*	0,051
exp_food	0,170	0,166	0,175***	0,187	0,182	0,188	0,146*	0,155	0,159
exp_NDG_oth	0,303	0,311	0,298	0,276	0,312*	0,270	0,338	0,348	0,339
exp_heat	0,009	0,009	0,010	0,006	0,011	0,008	0,007*	0,009	0,011
exp_DG_oth	0,307*	0,253	0,245	0,335*	0,273	0,277	0,232*	0,198	0,193

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions. ** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale. *** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en Région Flamande.

Inactif : (pré)pensionnés, étudiants, incapacité de travail, homme/femme au foyer ; actif sans emploi : chômeur.

Source : EBM 2002 – 2006.

Calculs : BFP.

Tableau A.2 Part des revenus des ménages par Région dans le revenu disponible et par statut socioprofessionnel du chef de ménage (Σ par type de ménages = 1)

	inactif			actif sans emploi			actif occupé		
	RBC	FL	WA	RBC	FL	WA	RBC	FL	WA
Activité économique	0,05	0,04	0,05	0,03	0,12**	0,06	0,81*	0,79	0,79
Patrimoine	0,19	0,21*	0,19	0,11	0,14	0,11	0,10	0,11	0,11
Allocations sociales	0,76	0,75	0,78***	0,83	0,73*	0,81	0,08*	0,09	0,09
Revenus transférés	0,01	0,01	0,01	0,02	0,02	0,02	0,00	0,00	0,00
Charges	-0,01	-0,01	-0,01	0,00	0,00	-0,01	0,00	0,01	0,01

* : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans les deux autres Régions. ** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée dans la Région de Bruxelles-Capitale. *** : la part des dépenses est significativement différente (seuil = 0.05%) de la part observée en Région Flamande.

Inactif : (pré)pensionnés, étudiants, incapacité de travail, homme/femme au foyer ; actif sans emploi : chômeurs.

Source : EBM 2002 – 2006.

Calculs : BFP.

Tableau A.3 Part des dépenses dans les dépenses totales : Classification Transport (Σ par type de ménages = 1)

	Total	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
exp_carE	0,087	0,095	0,040	0,101	0,099	0,074	0,057	0,096	0,102	0,081	0,063
exp_carT	0,007	0,005	0,005	0,008	0,008	0,011	0,009	0,008	0,007	0,010	0,008
exp_motoE	0,003	0,005	0,001	0,004	0,004	0,000	0,001	0,003	0,004	0,000	0,001
exp_motoT	0,00004	0,00003	0	0,0002	0,00004	0,00003	0,000008	0,0001	0,00003	0	0,00001
exp_gaso	0,012	0,010	0,009	0,013	0,013	0,014	0,014	0,012	0,013	0,015	0,013
exp_dies	0,014	0,008	0,003	0,019	0,015	0,012	0,009	0,025	0,019	0,011	0,009
exp_lpg	0,001	0,000	0,000	0,001	0,0005	0,000	0,0003	0,0010	0,0007	0,001	0,0003
exp_oil	0,0001	0,0000	0,0000	0,0002	0,0001	0,0002	0,0001	0,0002	0,0001	0,0002	0,0002
exp_rail	0,003	0,003	0,003	0,003	0,003	0,001	0,002	0,003	0,003	0,001	0,001
exp_BTM	0,002	0,005	0,004	0,001	0,001	0,000	0,001	0,002	0,002	0,001	0,002
exp_FoBi	0,002	0,001	0,001	0,004	0,004	0,003	0,002	0,001	0,001	0,000	0,000
exp_oth_tr	0,002	0,007	0,002	0,001	0,002	0,002	0,002	0,001	0,001	0,001	0,001
exp_gaz	0,017	0,020	0,024	0,013	0,017	0,017	0,020	0,007	0,015	0,010	0,021
exp_elec	0,023	0,018	0,021	0,022	0,021	0,026	0,024	0,026	0,023	0,031	0,028
exp_ene_S	0,001	0,000	0,000	0,001	0,000	0,001	0,001	0,001	0,001	0,002	0,001
exp_ene_L	0,011	0,003	0,004	0,008	0,005	0,016	0,012	0,021	0,014	0,030	0,019
exp_ene_oth	0,001	0,002	0,004	0,001	0,001	0,000	0,001	0,001	0,001	0,001	0,001
exp_health	0,045	0,042	0,059	0,037	0,037	0,058	0,061	0,038	0,042	0,063	0,062
exp_text	0,047	0,051	0,029	0,061	0,056	0,036	0,035	0,051	0,051	0,029	0,029
exp_food	0,160	0,146	0,174	0,152	0,156	0,169	0,167	0,159	0,159	0,179	0,177
exp_NDG_oth	0,331	0,337	0,297	0,349	0,347	0,302	0,315	0,342	0,338	0,284	0,297
exp_heat	0,009	0,007	0,008	0,009	0,009	0,009	0,009	0,011	0,010	0,012	0,009
exp_DG_oth	0,218	0,233	0,312	0,193	0,201	0,249	0,258	0,189	0,195	0,238	0,256

Source : EBM 2002 – 2006.

Calculs : BFP.

Tableau A.4 Part des revenus des ménages : classification transport

	Total	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activité économique	0,59	0,81	0,04	0,78	0,79	0,05	0,05	0,79	0,79	0,04	0,05
Patrimoine	0,13	0,10	0,17	0,11	0,11	0,19	0,20	0,11	0,11	0,19	0,17
Allocations sociales	0,27	0,08	0,78	0,09	0,09	0,76	0,75	0,09	0,10	0,78	0,78
Revenus transférés	0,002	0,004	0,013	0,004	0,005	0,010	0,008	0,001	0,003	0,003	0,010
Charges	0,01	0,00	-0,01	0,01	0,01	-0,01	-0,01	0,01	0,01	-0,01	-0,01

Source : EBM 2002 – 2006.

Calculs : BFP.

Annex 6 to the final report of the **LIMOBEL** project (Long run impacts of policy packages on mobility in Belgium), financed by the Belgian FPS Science Policy.

(Contract SD/TM/01B)

NODUS: Maps of the road, rail and inland navigation network

Bart Jourquin, Davy Dewaele
FUCaM

January 2011

Figure 1: Belgian road network

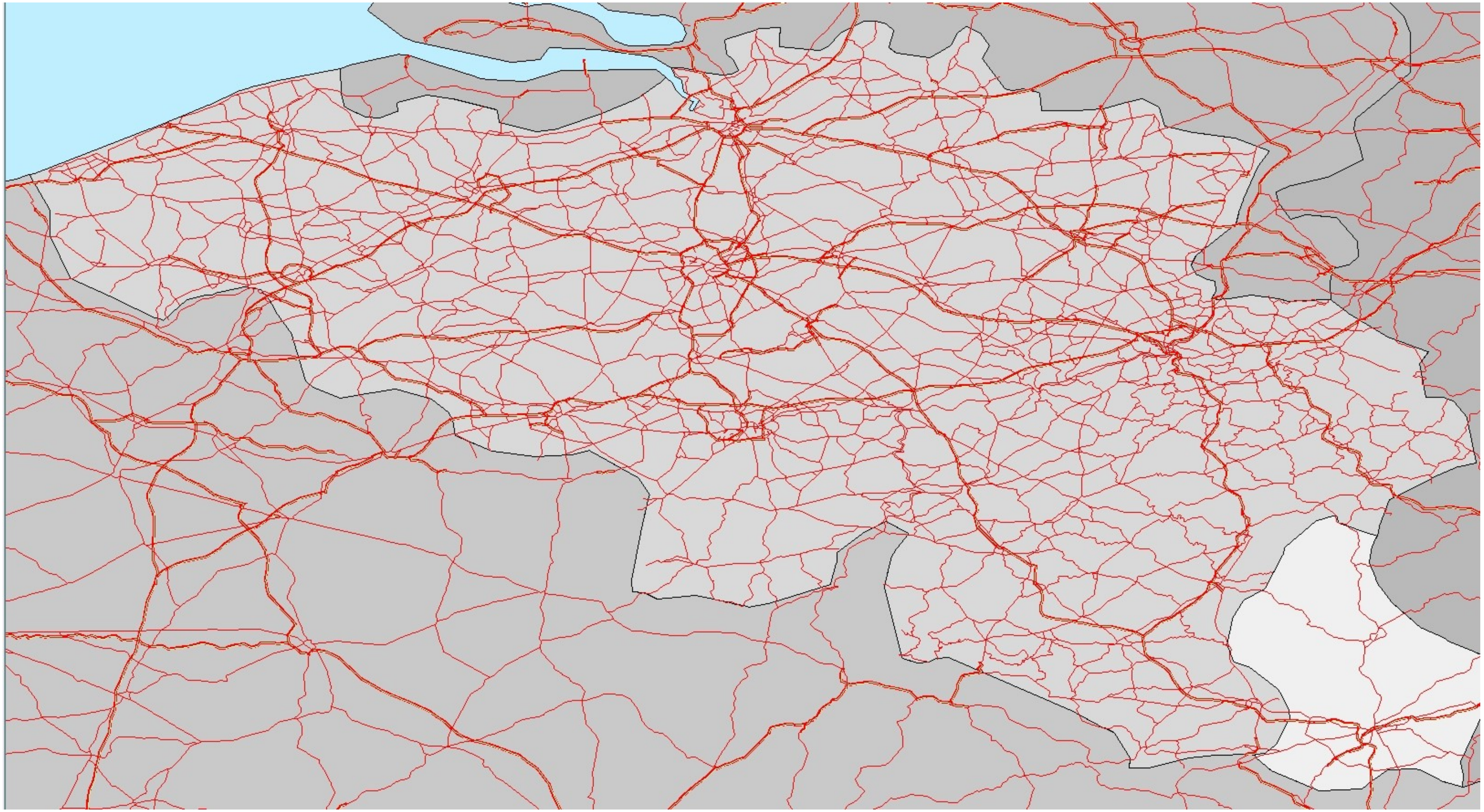


Figure 2: Belgian railways network

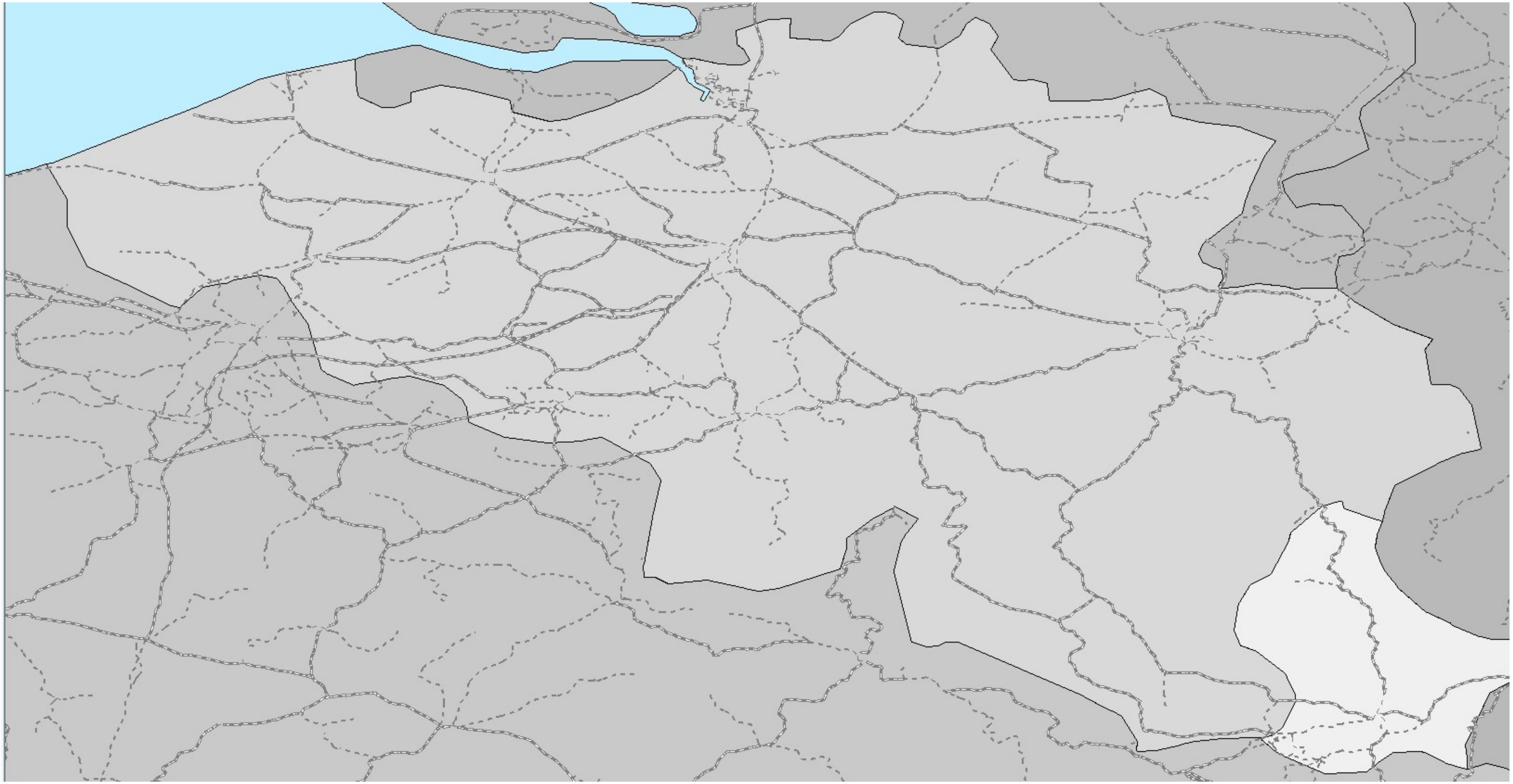
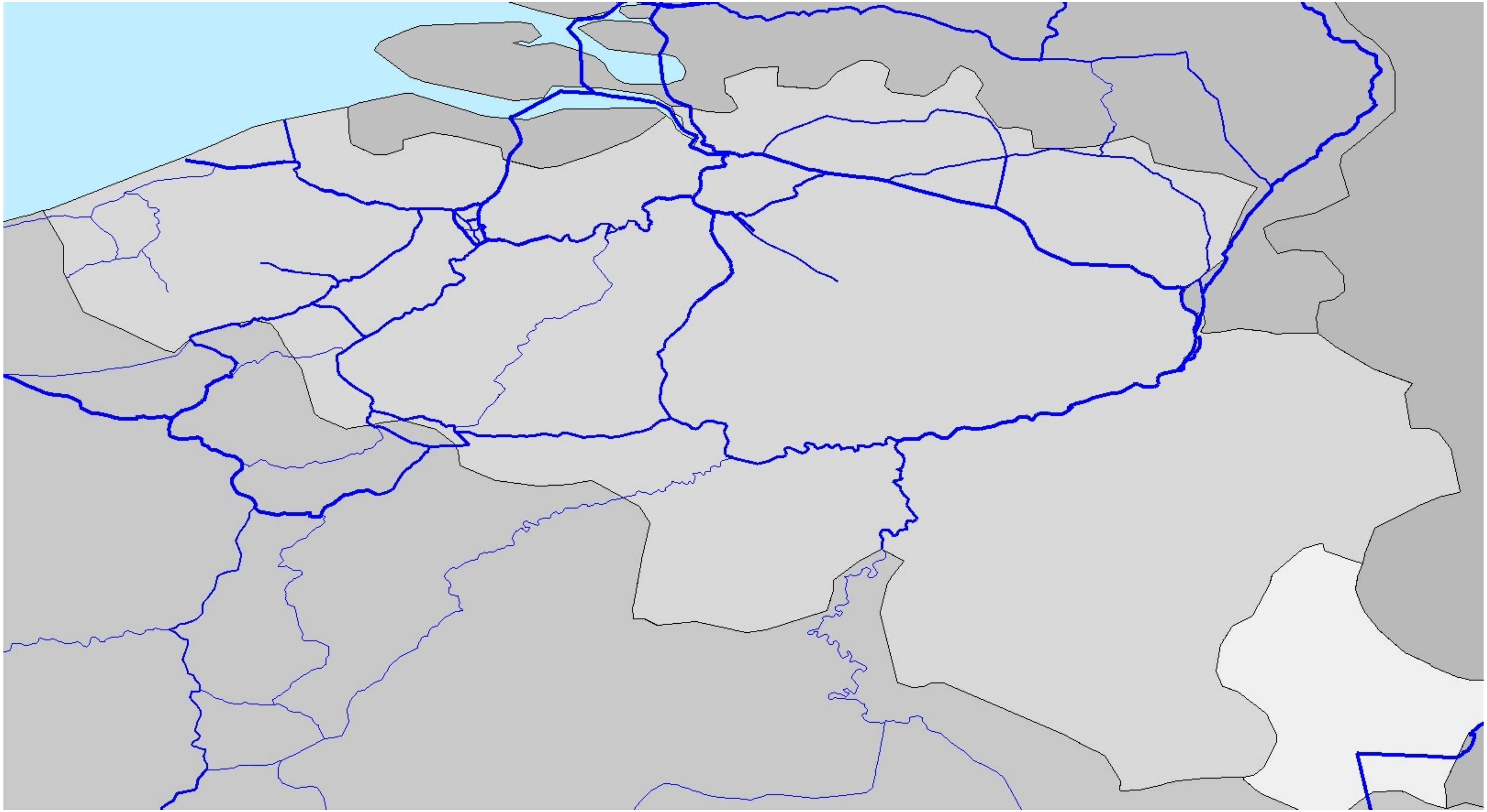


Figure 3: ***Belgian inland waterways network***



Annex 7 to the final report of the **LIMOBEL** project (Long run impacts of policy packages on mobility in Belgium), financed by the Belgian FPS Science Policy.

(Contract SD/TM/01B)

LIMOBEL Annex 7

Minutes of the meetings with the LIMOBEL follow-up committe

January 2011

LIMOBEL

Report of the meeting of the follow-up committee - 29 May 2009

Present:

Damien Borsu, Laurence Declock, Laurent Demilie, Ina De Vlieger, Georges Jamart, Inge Mayeres, Marie Vandresse, Tania Van Mierlo, Denise Van Regemorter,

Excused :

Caroline De Bosscher, Caroline De Geest, Bart Jourquin, Sara Ochelen, Stef Proost, Philippe Toint, Marie-Rose Van den Hende, Greet Van Laer, Vincent van Steenberghe

Agenda

- Presentation of the current state of work in the LIMOBEL project by the three research teams (FPB, GTM, VITO)

    - long-term economic model

    - network model

    - environmental impact assessment model

    - Presentation of the links between the three LIMOBEL model components by means of a policy example

- Planning for 2009

- Participation of the follow-up committee in the set-up of the policies to be simulated with LIMOBEL

A copy of the powerpoint presentation is included as an annex.

The following points/questions were raised during the discussion on the current state of work in the LIMOBEL project:

Regarding the long-term transport projection model (PLANET2)

Does the CGE model take into account both transport services that are provided by the transport sectors, as well as the transport services for own account?

> *The transport services that are included in the model are an aggregate of the two types. The transport sectors are therefore defined in a broader way than what is included in the National Accounts. In the social accounting matrix the inputs for the production of transport services for own account are assigned to the transport sectors, and the output value of the*

transport sectors equals the sum of marketed transport services and transport services for own account.

Regarding the environmental impact assessment model (E-motion)

- Does VITO use the Ecosense model to determine the environmental damages related to air pollution?
    - *Yes. However, VITO takes into account its own assessment on background concentration of pollutants*
- It was suggested to ensure maximal comparability with the EMMOSS model
- It was clarified that the MIMOSA4 model forms part of the E-motion model

Regarding the network model (NODUS)

Three interrelated questions were raised:

- Is the impact of growing transport flows on average speed (congestion levels) taken into account; If so, how is this done?
- Is infrastructure in NODUS adjusted when transport flows are growing?
- Is it possible to use NODUS to identify which parts of the infrastructure will form bottlenecks in the future, given growing transport flows? This information would be useful to define priorities for infrastructure investments in the future.

An answer to these questions will be sent by e-mail to the members of the follow-up committee.

Participation of the follow-up committee in the set-up of the policies to be simulated with LIMOBEL

The members of the follow-up committee are invited to make suggestions for policies to be simulated within the LIMOBEL project. In the powerpoint presentation a short overview was made of different policies and the identification of possible impacts in the three LIMOBEL model components. The LIMOBEL framework is most appropriate to evaluate larger scale policy reforms that can be expected to have an impact not only on the different stages in transport decision making of households and firms (transport generation, trip distribution, modal choice, time choice, vehicle choice, etc.) but also on the economy in general.

Suggestions can be sent to Inge Mayeres (im@plan.be) until 30 September 2009. The proposals will be discussed in more detail at the next meeting of the follow-up committee, after which a selection will be made.

Annex

- The powerpoint presentation presented at the meeting

LIMOBEL

Report of the meeting of the follow-up committee – 5 January 2010

Present:

Damien Borsu, Caroline De Bosscher, Caroline De Geest, Laurent Demilie, Davy Dewaele, Ina De Vlieger, Georges Jamart, Bart Jourquin, Fre Maes, Inge Mayeres, Hans Michiels, Paul Schroé, Orane Vanmeenen, Alex Van Steenbergen

Excused :

Eric Cornélis, Sara Ochelen, Marie Vandresse, Tania Van Mierlo, Denise Van Regemorter, Vincent van Steenberghe

Agenda

- Presentation of the current state of work in the LIMOBEL project by the three research teams (FPB, GTM, VITO)

  - long-term economic model
  - network model
  - environmental impact assessment model

- Participation of the follow-up committee in the set-up of the policies to be simulated with LIMOBEL

The discussion on the current state of work in the LIMOBEL project:

- Fuel tourism is important in the case of road freight transport, and may have a substantial impact on government revenues. How is this incorporated in the model?
- The marginal external costs of PM emissions are average costs and do not make a distinction between emissions in urban and non-urban areas.
- The marginal external costs of NOx emissions that are related to the formation of sulphates and O3 are negative. Because of this, NOx emissions are associated with a marginal external benefit in 2007. In future years (2020 and 2030) they are associated with a marginal external cost because the costs related to the formation of nitrates and PM10 outweigh the benefits related to the formation of 03 and sulphates. The non-convexities in O3 formation are well known. Still, the follow-up committee suggests that this result should be analysed further. For instance, is it due to the way in which the marginal external costs are calculated (20% reduction in transport emissions of NOx)?
- Bart Jourquin points out that for passenger rail transport in the network model the trip distribution matrices are available only for commuting and school transport. Up to now no data could be obtained from the NMBS/SNCB allowing to construct similar matrices for the other trip purposes.

TO DO:

- Describe whether and how fuel tourism is incorporated in the model
- Carefully analyse the results for NOX emissions
- Send the report about the calculation of the marginal external air pollution costs to the follow-up committee

The discussion of the selection of policies/policy packages

- A list of policies that could be interesting to investigate was proposed by Laurent Demilie and Tania Van Mierlo – they are included in an annex to this report.
- Fre Maes states an interest in policy simulations related to the non-ETS emissions of greenhouse gases – with a time horizon of 2020
- The follow-up committee states an interest in the simulations of policy packages rather than individual policies. However, it could be interesting also to analyse the contribution of individual policies to the global policy package.

TO DO:

The currently proposed list of policies will be sent after the meeting to the members of the follow-up committee. Comments as well as additional policy proposals can be sent to Inge Mayeres (inge.mayeres@vito.be) until **13 January**.

Your suggestions about additional policy proposals can be done in the following framework:

- Description of the policies

- Objectives of the policies

- Time horizon

- Expected impacts on the three components of LIMOBEL (PLANET2, NODUS,E-MOTION)

Please remember that the LIMOBEL framework is most appropriate to evaluate larger scale policy reforms that can be expected to have an impact not only on the different stages in transport decision making of households and firms (transport generation, trip distribution, modal choice, time choice, vehicle choice, etc.) but also on the economy in general.

Annexes:

- The powerpoint presentations presented at the meeting
- A list of policy proposals by Laurent Demilie and Tania Van Mierlo

LIMOBEL

Report of the meeting of the follow-up committee – 2 July 2010

Present:

Ivo Cluyts, Caroline De Geest, Laurent Demilie, Davy Dewaele, Ina De Vlieger, Dominique Gusbin, Georges Jamart, Inge Mayeres, Marie Vandresse, Alex Van Steenbergen

Agenda

- Presentation of the current state of work in the LIMOBEL project by the three research teams (FPB, GTM, VITO)
    - long-term economic model
    - network model
    - environmental impact assessment model
- Participation of the follow-up committee in the set-up of the policies to be simulated with LIMOBEL

Main points of the discussion that followed these presentations

- The follow-up committee pointed out the discrepancy between the marginal external costs of NOx that were presented and the results of the recent MIRA study. VITO will compare the two approaches and make adjustments where necessary.
- As regards the policy scenarios, an overview was made of the suggestions made by the members of the follow-up committee after the previous meeting. The proposal to base the selection on two criteria was accepted. The criteria are: (i) is the large LIMOBEL framework required for these analyses, or can they better be done by smaller models? (ii) is it possible to analyse the policies within the LIMOBEL framework? Road pricing and changes in transport costs due to infrastructure changes were considered to be suitable research topics.
- Reference was also made to the PROLIBIC project that provides further resources to investigate policy packages.