Brussels Case Study

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1 Introduction

The Brussels case study consists in the development of an UrbanSim model covering Brussels and its surroundings. A MATSim travel model has also been developed for Brussels, to be plugged with the UrbanSim model, into an integrated land-use/transport model. The objectives of this case study were to test the performance of UrbanSim as a land-use microsimulation tool and to assess policy impacts for a few policy scenarios.

Unlike the two other case studies, no full-scale operational UrbanSim model of Brussels existed at the beginning of the SustainCity project. A prototype model had been built previously, in order to test the software abilities, but it had been developed at a very aggregate level and was unable to provide meaningful simulation results (Patterson & Bierlaire 2008). As the new model was planned to be far more

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ambitious and more disaggregated (both at the spatial level and at the level of the socio-economic segmentations), it has been developed on a completely new basis, requiring a completely new data collection process. New models have been developed, parameters have been estimated, validation checks have been performed, by comparison with observed data or with results from existing validated studies (notably for the transport side). Eventually, three scenarios have been simulated, a business-as-usual scenario and two policy scenarios. During this whole process, technical difficulties have been met and were overcome, in the limits of the scope of the project: mainly difficulties in the data collection, in the validation process and in the simulation runs. Due to the high number of variables to obtain at a very fine level of spatial analysis, some results are only partial and should be interpreted carefully. This is further detailed when discussing the results and the conclusions.

Specifically, to achieve the objectives of the case study, the following steps were carried out:

- collect the required data, estimate the sub-models making part of the UrbanSim model and develop a comprehensive UrbanSim model;
- use MATSim as a travel model plug-in to UrbanSim;
- define and simulate a set of policies with the integrated land-use/transport model;
- calculate indicators to assess the policies;
- assess the performances of the simulation tool, notably on the following aspects: difficulty of the overall calibration, quality of the reconstitution of the base year situation, sensitivity of the model (direction and magnitude of the effects, elasticity), remaining limits and weaknesses.

This chapter contains the followings:

- a description of the city and of the issues it is currently facing in the field of land-use and transport (Section 2);
- a general description of the Brussels model (study area, base year, other horizons considered, structure of the model) (Section 3);
- a description of the data that were available and were used for the modeling, and their limitations (Section 4);
- a description of the UrbanSim sub-models (Section 5) and of the MATSim model for Brussels (Section 6);
- the reconstitution of the base year 2001 and of the validation year 2007 (Section 7);

- a description of the policies that were simulated (Section 8), and their results (Section 9).

Three partners were involved in the study: STRATEC, EPFL (École Polytechnique Fédérale de Lausanne) and UCL (Université Catholique de Louvain). The road traffic model, MATSim, and the mode choice model were developed by TU Berlin (Technische Universität Berlin).

2 The Brussels context

In the Brussels city itself, an old industrial axis along a canal surrounded by poor neighbourhoods with different ethnic communities makes its way through the whole city, cutting it in two parts. For some years now, this area is in a process of renewal, with important residential and office developments.

Another important feature is that Brussels, as many other European cities, undergoes a continuous out-migration of middle class families to the suburban areas, yet for several decades, which causes urbanization of previously open spaces, commuting by car and traffic congestion. In reply to this, the Brussels-Capital regional authorities implement policies to improve the residential attractiveness of the region. On the other side, this out-migration process is compensated by a high growth of lower-income population.

Brussels also has to manage important administrative functions (including the European and other international institutions) and to elaborate strategies to integrate these functions in the city in a way both harmonious and efficient.

In the context of transport infrastructure, one of the main future projects is the Regional Express Railway Network (Réseau Express Régional - RER), to be fully implemented by 2025, which will significantly improve the accessibility between the centre and the suburban areas, and is expected to have effects on household and economic activity location.

Another important point here is that, the three regions making up the Belgian federal state – the Brussels-Capital, the Walloon and the Flemish Regions – have committed themselves to drastic reductions in their greenhouse gas emissions. This objective appears to be reachable only if it is supported by strong land use and transport policies.

In brief, some important issues that the city is currently facing are the following ones:

- the housing supply to be developed in the Brussels-Capital Region to meet the needs of the demographic growth foreseen for the next decades;

- the densification of office districts and namely of the European institutions district;
- the possible implementation of an urban congestion pricing scheme;
- the funding of the development of the public transport network and services;
- the pricing of the future RER (what would be the consequences of different pricing strategies in terms of modal shift from car to the RER and in terms of household and firm relocation?).

Consequently, from the very beginning of the SustainCity project, the policy scenarios which were envisaged to be simulated with UrbanSim were: densification policies and urban road pricing.

3 General structure of the Brussels UrbanSim model

3.1 Study area

In the project, functional and transportation criteria were used to define the study area. It is hence much larger than the purely morphological and functional urban agglomeration.

The central part of the urban agglomeration corresponds to the Brussels-Capital Region (hereafter BCR). Then it spreads beyond the limits of the BCR, over a part of the Flemish Region and Walloon Region. The whole study area corresponds to a set of 151 municipalities (or "communes") around Brussels (Figure 1) and includes about 3 million inhabitants, which is much larger than the BCR (19 municipalities and about 1 million inhabitants).

More precisely, the criteria used to delineate the study area are the following: (1) all municipalities that will be affected by the RER network. This "RER zone" is officially defined as "*all municipalities in about 30 kilometres from Brussels*" (Belge 2004), and represents 126 municipalities. (2) In addition, 21 municipalities, mainly in the northern and north-western part of the study area, were added because they were included in the study area for the evaluation of the effects of the RER network by Stratec (Stratec 2003, 2005, Boon & Gayda 2008). (3) Finally, four municipalities (Landen, Linter, Hannut and Wasseige) located at the south-eastern extremity were added since they are part of the Metropolitan Labour Area of Brussels defined by Van Hecke et al. (2009). We end up with 151 municipalities.

This study area is far larger than the delineations usually considered when studying Brussels (see Dujardin et al. (2007), Thomas et al. (2012) for reviews). Hence, the influence of the city center is "diluted" by two factors. First, several municipalities within the study area are in the commuting hinterland of other cities than

Brussels. This is in particular the case in the northern part, due to the proximity of Antwerpen and Ghent. Secondly, other municipalities, mainly in the south-eastern part of the study area are more rural or periurban. Consequently, in terms of urban model, this study area does not correspond to an urban region, but rather to a polycentric area (this issue is discussed in details in Chapter 1.3?). To mitigate that problem, it has been decided to use as much as possible the delineations of urban areas proposed by Van Hecke et al. (2009) and macrozones for the evaluation of the results of the model (and the scenarios). In any case, the indicators computed for the policy evaluation were at least computed both for the whole study area and for the BCR, these latter results being not affected by a border effect.

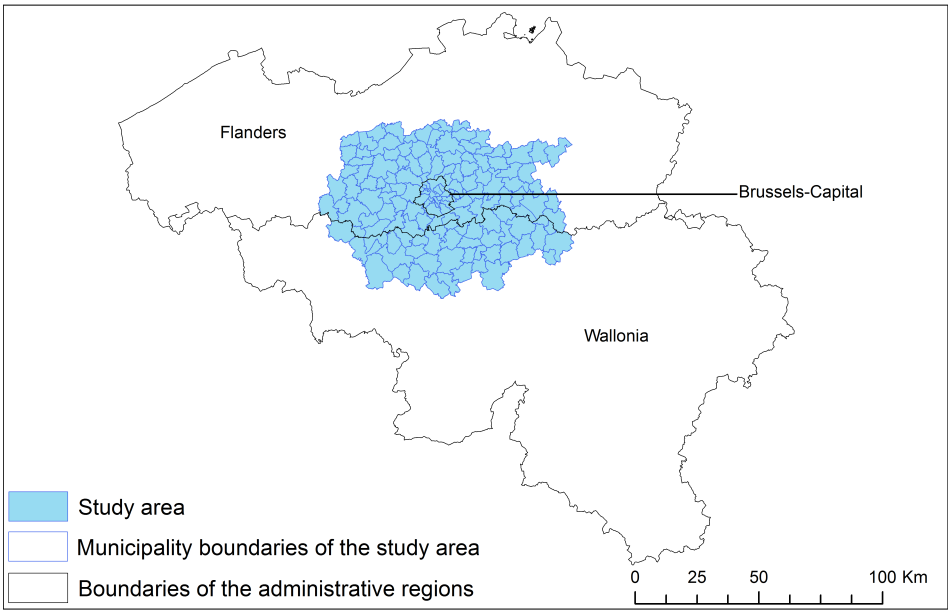

Figure 1: Commune boundaries of the study area of the Brussels case study (Source: IGN, Map : Stratec, 2011).

3.2 Zoning system

With regard to the spatial basic units, an UrbanSim model can be built at zone level, plot level or gridcell level. “Zone” here means any irregular polygons, for example the transport zones usually used in transport models or administrative units. For the Brussels model, considering the available data, it was decided to develop a zone-based model. The different levels of spatial disaggregation are the “municipalities” or “communes” that divide the study area in 151 units and the “zones” or “statistical sectors”[1] that divide it in 4945 units. Note that the terms “municipality” and “commune” are equivalent. In the chapter, the term "municipality" will be used.

3.3 Time horizons

The base year of the model is 2001 when the last National Population and Housing Census was carried out. The sub-models making up the Brussels model were therefore estimated on 2001 data. The year 2007 was used for validation purpose. The scenario simulations were carried out up to the horizon 2020.

3.4 Development of the model

The development of the model includes four main steps: (1) the definition of the overall structure of the model (which submodels to include, which segmentation of population, employment and buildings to adopt), (2) the building of the databases of agents and supply units constituting the structure of the model, (3) the estimation of the parameters of the submodels, and (4) checks and validation of the model, as far as it is possible with the available data and resources. This last step consisted in (1) checking the reconstitution by the model of the 2001 observed situation on various aspects (population, employment and transport indicators), and (2) comparing the 2007 modelled situation with the 2007 observed situation (population and employment).

3.5 Agents, supply units and their segmentation

According to the basic principles of UrbanSim, the skeleton of the Brussels model consists in three databases containing the agents whose behaviour is simulated and the supply units: a household database, a job database and a building database.

Households are characterized by their size, income level, number of children, number of workers and education level of its members. Table 1 describes the values for each attribute level .

On the employment side, ten activity sectors were defined as shown on Table 2.

Buildings were divided between residential and non-residential buildings. Residential buildings were classified in three types of single-family houses (fully detached, semi-detached and attached) and one type of multi-family units (apartments). Each zone is assumed to have one representative building by type (with a variable number of units in each of them), generating a total of 19780 possible location types (combinations of zones and building types). Ten types of non-residential buildings were considered, each being specific to an economic activity type. Table 2 summarizes the types of dwelling units and other buildings considered in the model

[1]The “statistical sectors” are official Belgian statistical spatial units, they are subdivisions of the municipalities.

Table 1: Household attributes

Attribute	levels
Income level of the household (inc_h)	1 (0-1859 Euros)
	2 (745-1859 Euros)
	2 (1860-3099 Euros)
	4 (3100-4958 Euros)
	5 (>4959 Euros)
Household size ($\mathrm{hh\_size}_h$)	1,2,3,4,5+
Number of children ($\mathrm{children}_h$)	0,1,2+
Number of workers ($\mathrm{workers}_h$)	0,1,2+
Number of cars (cars_h)	0,1,2,3+
Number of people with university degree (univ_h)	0,1,2+

Table 2: Building types

type id	description	category
1	isolated houses	residential
2	semi-attached houses	residential
3	attached houses	residential
4	apartments buildings	residential
5	agricultural	non-residential
6	quarrying, mining	non-residential
7	industry	non-residential
8	office (private sector, including bank)	non-residential
9	shops, retail	non-residential
10	hotels, bars, restaurant	non-residential
11	government and public service	non-residential
12	education	non-residential
13	health	non-residential
14	leisure activities	non-residential

3.6 Sub-models

The UrbanSim model is composed of the following submodels: a real-estate price model, for the dwelling units; location choice models, on the one side for the households, on the other side for the employment (by activity sector); location choice models for the development projects, again for the residential projects and the non-residential projects ; and a workplace choice model simulating how workers choose their workplace.

4 Data collection

As seen above, one of the main characteristics of UrbanSim is the requirement of disaggregate data. The three main databases (households, jobs and buildings) have to be provided for the base year (2001) and, besides that, total figures of households and jobs have to be provided for each simulation year (i.e. up to 2020, in the Brussels case). Additionally, a few other databases are required: data on the development constraints and on the past history regarding the development projects. A few general (non spatially disaggregated) parameters are needed, such as agent relocation annual rates and average building vacancy rates. Eventually, specific data for the MATSim road traffic model and the mode choice model are also required.

According to the modelling dates, data was mainly collected for the years 2001 and 2007.

This section describes the main data sources that were used. In some cases, it also specifies some particular data processing that was performed.

4.1 Household data

In Belgium, the most exhaustive data source on population is the National Population and Housing Census, knowing that the last census was performed in 2001[2] (Vanneste et al. 2007, Verhetsel et al. 2009, Thomas et al. 2011). Beside the census, other rich sources exist: the National Population Register (yearly updated), the Crossroads Databank for Social Security, which combines itself various sources and provides an overall picture on the activity of the population, at individual level, and the National Labour Force Survey.

For the base year, a set of data from the 2001 census was obtained at an aggregate level from the Directorate-General for Statistics and Economic Information (Federal Public Service (FPS)-Economy).

The first idea was to request an extract of the census, with data at an individual level. However, the Belgian administration refused to provide these data because

[2]Precisely the census is dated 1st of October 2001.

of privacy issues. Consequently, it was decided to build from the aggregated data a "synthetic population" of individual households, whose location is given at the zonal level, using a Markov Chain Monte Carlo simulation based approach (Farooq et al. forthcoming). The generation of synthetic populations is a common practice in land-use/transport modelling, especially when individual level data are not available due to strict privacy policies. In the US for example, it often happens that modellers do not have access to micro census records, and therefore must use synthetic population generation algorithms to create the data. For more details on the synthetic population, see Chapter 2.1 or 2.2 ?.

Generally speaking, the main limitations of the 2001 census are that the rate of missing questionnaires (about 5%) is strongly related to the socio-economic level and that the survey is limited to persons legally registered in the National Population Register which leads to a certain lack of information, especially in big towns like Brussels.

Data on household income was available by statistical sector for the year 2001, from fiscal statistics set up by the FPS-Economy. This database provides average and median income at the level of the statistical sector for whole Belgium, on the basis of income tax return, as well as the interquartile difference, the interquartile coefficient and the interquartile a-symmetry. It has to be noted that the number of income tax returns (or "fiscal households") is not always equal to the number of "social" households, in a statistical sector or a municipality. Indeed, there is one income tax return by fiscal household; and a fiscal household cannot include more than 2 persons having an income. Also, data are only available for statistical sectors that have more than 30 income tax returns.

For the validation year, population data were collected from the National Population Register, which provides the total population at the statistical sector level, classed by age group (of 5 years intervals), on the 1st of January 2008.

Data on activity of occupied active people, at the municipal level, were taken from the Crossroads Bank for the Social Security (Office National de l'Emploi (ONEM)). This database gathers data on employed, civil servants and self-employed persons at the municipal level on the 31st of December 2007. All the information is registered at the home place of the persons.

4.2 Employment data

Data on employment for the base year and the validation year were collected from the same sources.

In general, data on employment are less accurate than data on population for various reasons: the level of spatial disaggregation is less detailed; often, a compilation of different databases (corresponding to different status: employees, self-employed workers, civil servants, etc.) has to be done in order to give the full picture, but with risks of double counting or missing data.

For the Brussels model, the main data sources on employment were the National Social Security Office for Employees and Civil Servants (Office National de Sécurité Sociale (ONSS)) and the National Institute for Social Security for self-employed persons (Institut National d'Assurances Sociales pour Travailleurs Indépendants (INASTI)). The databases were available from the FPS-Economy for each year until 2009.

The ONSS database includes all employee and civil servant jobs (i.e. all the jobs whose workers take part in the belgian employee social security system) at the municipal level on 30th of June of each year. The employees are registered at their work place, not at their place of residence.

The INASTI database describes the activity of self-employed persons at the municipal level (or district, province, region, national level) on the 31st of December of each year. The self-employees are registered at their company address. This leads to a difficulty: the address is the place where the company is registered, but in many cases this address corresponds to the home place of the self-employee and not to his actual work place.

Further sources were exploited for estimating figures regarding the international jobs. The Brussels Institute of Statistics (Institut Bruxellois de la Statistique (IBSA)) provided data on jobs in international public institutions for the BCR (i.e. the European Commission, the Committee of the Regions, the European Council, the European Parliament, the NATO and the Western European Union) from 2001 to 2009. Estimation on international jobs in the BCR for 2001, 2005 and 2011 were also gathered from the Stratec study "Updating and adaptation of the Urban Transport Plan for the Brussels-Capital Region" (Stratec 2006).

Data from the national Labour Force Survey (LFS) was also used. The LFS is a socio-economic household survey conducted by the FPS-Economy, whose primary objective is to classify the population of working age (aged over 15) into three exhaustive and distinct population categories (employed, unemployed and inactive). It provides, on each of these categories, descriptive and explanatory data. There is specific information concerning the home-based work status. The information is collected through face-to-face interviews and is valid for the 31st of December of each year, from 1999 to 2008. Households with only inactive members (aged over 64) may also be interviewed by telephone. The sample size is of 90,000 inhabitants aged 15 and over. Roughly, the representativeness of the sample is sufficient for providing ratios, percentages, etc, by administrative Region, but not at a finer spatial level.

Employment data was available only at the municipal level. Distribution within zones and buildings was done through a Monte Carlo simulation, following the observed distribution of available non-residential surface by zone and building type.

The number of activity sectors was assumed to be equal to the number of types of non-residential buildings, meaning that each type of job can be located in a specific type of building (e.g. jobs in industrial sector can be located in industrial buildings).

4.3 Land use and real estate data

Informations on land use and buildings are based on the *Land Registry* database. It is a cadastre of real estate goods, provided by the “Administration Générale de la Documentation Patrimoniale”, at the plot and building levels. The database is federal and hence the same definitions of the variables are used in all three Belgian administrative Regions (since Brussels sprawls out of its administrative boundaries, these three regions are present in the study area). Its purpose is fiscal and juridical: it provides information for calculating the taxes to be paid by the owner of the plot/building(s). This ensures that all plots are taken into consideration (no sampling) but also implies some drawbacks.

For the entire country, 221 types of plots are defined (Table 3): 157 for built-up plots and 64 non-built. For instance, the most frequent types among the 2,047,675 plots in the study area are “houses” (42 % of built-up plots) and “farmland” (44 % of non-built plot). Data are geocoded allowing for crossing them in a Geographical Information System (GIS). Note that the alpha-numerical ID of each plot (see 3) includes the ID of the administrative unit (municipalities and statistical sectors) to which it belongs.

2009 is the first year for which digitalized data were available. On this basis, the situation in 2001 was estimated by removing all buildings having a construction date posterior to 2001. The different plot types were manually re-aggregated into 14 categories to define the buildings represented in the model (see Table 2).

For each building type, the *Land Registry* database allows to compute the total surface occupied in t_0 by a building type *i* in the zone *j*. This surface is hereafter referred to as the *actual* land use. Note that for residential buildings the value of this actual land use is, in UrbanSim, the total number of residential units rather than the total surface. Hence, for such buildings, the number of plots is used, instead of the sum of their surface.

The database has to be interpreted with caution because of the following reasons:

- Types of land use were too numerous to be relevant as UrbanSim’s buildings. Hence reclassification was absolutely required, but some discrepancies can be present in this reclassification.
- Types of land use are not identified by a word (f.i. “houses” for houses plot) rather than an alpha-numerical id. Moreover, the word used changes accord-

Table 3: Land Registry data for each plot.

Field	Description	Note
CaPaKey	Identification code for the plot	
Nature	Type of plot	
IndiceCC	Classification index	Only for built-up plots
Type	Construction type (A : 2 side walls, B : 1 side wall 3 façades), C : isolated building (4 façades))	Only for built-up plots
AnnéeCstr	Year the construction was finished	Only for built-up plots
AnnéeMod	Year of last renovation	Only for built-up plots

ing to the linguistic region where the plot is located, e.g. houses are registered as "maisons" in the french-speaking region and "huis" in the the dutch-speaking region. This may also lead to errors in the reclassification process;

- Errors on the date of construction may also be observed, especially for renovation or extensions. This can be due to the fiscal nature of this database (fraud) but also by a lack of rigorous follow-up strategies of some local sections of the Administration. Hence, errors will be much smaller on recently built buildings than on old buildings;

- Single family houses plots generally encompass in a single plot both the footprint of the house and the garden. Nevertheless, looking closer at the data it was noticed that some houses plot follow the exact limit of the house, and that this plot is surrounded by a plot identified as "garden". Hence, it is not accurate to compute the built-up areas on the basis of the plot. Rather, an overlay of plot and buildings were made, and built-up surfaces were computed using the footprint of these buildings;

- Some features are not included in the *Land Registry* database, such as the transportation network.

UrbanSim also requires information on real estate prices. Data on housing real-estate prices were available from the FPS-Economy at the municipal level. The database provides the average price of housings sales by type of dwelling (2, 3, or 4 front-wall houses and flats) on the 31st of December from year 1985 to 2008. It gives the number of sales and the total value of these transactions, on which the average selling price is computed.

4.4 Development constraints

Development constraints are not implemented explicitly in the current version of the model. Rather, the *actual* and *potential* area occupied by each building type in each basic spatial units are defined within the building table. This *potential* land use is defined as the total surface (footprint) that can be affected to a building type i in the zone j, whether the corresponding plots are vacant or already built. Note that the *developable* surface, although not represented explicitly, is thus simply the difference between *potential* and *actual* land-use.

The sources used were the Regional Master Plans of Wallonia, Brussels and Flanders. They define the type of buildings allowed on each plot: agricultural land, residential areas, industrial areas, natural areas, and so on (these data are geocoded and can be overlaid with the plot/building(s) from the Land Registry database). These databases suffer the following drawbacks:

- Since they are regional, the definitions used in one Plan do not converge completely with those of the two other Plans. Although main categories (e.g. agricultural areas, residential land-use, industrial land-use, etc.) are comparable, some discrepancies exist;
- The categories defined by the Regional Master Plans are not mono-functional. For instance, it is allowed to build small retail buildings in areas affected to residential developments;
- The areas defined by the Plans are subject to changes and/or revisions.

4.5 Development events history

Development events have been extracted from the *Land Registry* database, by selecting all plots having a construction date from 1991 to 2001 included.

4.6 Data for the transport model

A MATSim model was also developed for Brussels: this has been done in order to stay within an overall consistent microsimulation framework for both land-use and transport. However the MATSim model has been developed with limited resources and has not been calibrated as far as it would have been desirable. As a reference for comparison, an existing model was used, the IRIS 2 transport model of the BCR (Stratec 2006), covering an area similar to the SustainCity study area. The IRIS 2 model was developed with the SATURN software for the road traffic model, which is a dynamic traffic model, and with the VISUM software for the public transport model.

The MATSim road traffic model requires a road network which was here built using the data from OpenStreetMap (2013). It consists of 10,861 nodes and 19,830 links.

It also requires a list of persons (workers) with information about their household (origin) and job (destination) location that was simulated following the synthetic households and observed origin-destination matrices for trips. The 2001 census provides information on home-to-work relationships by giving a matrix of persons distributed according to their residence place and their working place at the municipal level.

The car kilometer costs for different years of simulation were estimated based on vehicle operating costs and fuel costs gathered from different sources:

- FPS-Economy for the official prices of fuel from 1988 to 2013;
- Federal Planning Bureau (FPB)[3] for the predicted evolution of fuel prices until 2030;
- MEET (1999) for the curves of fuel consumption depending on speed by vehicle type;
- FPS-Finances for the vehicle operating costs;
- Febiac (Belgian federation of automative and cycle industry) for the distribution of cars according to the type of fuel in 2001.

For the mode choice model in MATSim, data on public transport travel times, public transport travel distances, public transport kilometer costs and car kilometer costs were collected. The public transport data were collected from time-schedules.

In the IRIS 2 model, 7 macrozones were defined (Figure 2). These macrozones are arranged concentrically around the city of Brussels: 1 corresponds to the historical city centre; 2 and 3 to the rest of the BCR; 4, 5 and 6 to the periurban area and 7 to the rest of Belgium. For the validation of the model, car travel times and mode shares were computed for the relationships between the 7 macrozones and were compared to the results of the IRIS 2 model.

4.7 Other data

The macroeconomic data required by UrbanSim are the annual household control totals, the annual employment control totals, the annual household and job relocation rates and the target building vacancies.

[3]The Federal Planning Agency is the Belgian public agency in charge of the official demographic and socioeconomic projections as well as the projections regarding socioeconomic and environmental policy issues.

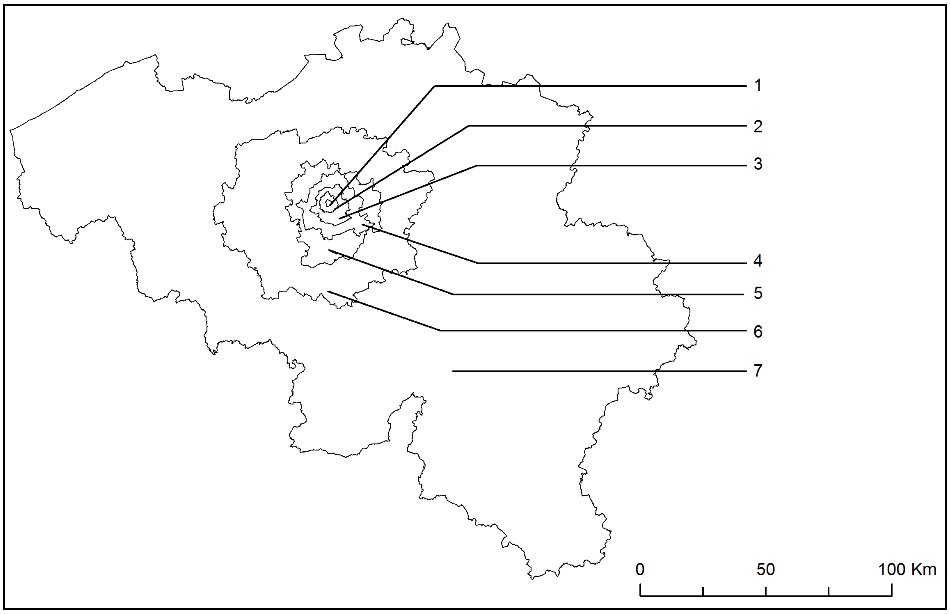

Figure 2: The 7 macrozones as defined by Stratec (2006) : 1 corresponds to the most central zone and 7 to the rest of Belgium.

The annual household control totals are the aggregate targets for households (total number of households for the study area) for the years of simulations (from 2001 to 2020). The data were estimated based on the 2001 population data census (FPS-Economy), on the 2007 National Population Register (FPS-Economy), on population projections (FPB), and on the evolution of the annual average household size between 1991 and 2008 per Region (FPS-Economy).

The annual employment control totals are the aggregate targets for employment (total number of jobs for the study area) by sector and for the years of simulations (from 2001 to 2020). The data were obtained from FPB. Data on activity of self-employed workers and employee/civil-servant jobs were available from 1995 to 2016 at the regional level and from 2017 to 2020 at the national level.

The main source for vacancy rates of dwellings was a 2005 publication from RBDH (Rassemblement Bruxellois pour le Droit à l'Habitat) which provides estimations based on water consumption for the BCR in 2003.

The main sources for the vacancy rates of buildings dedicated to economic activities were the following publications: the Retail Observatory (2005, 2007 and 2008), the Office Property Observatory (2007, 2008, 2009 and 2011) and the Production Activities Observatory from 1997 to 2011. These reports are produced by the BCR Administration and the Brussels Regional Development Agency (BRDA).

Estimates of the household annual relocation rates were found for Belgium in Bodeux (2002) and for the Walloon Brabant, all of whose municipalities belongs to the study area, in Zitouni et al. (2004) (Table 4).

Table 4: Estimates of the household annual relocations rates

Source	Year	Study area	Annual households relocation rate
Bodeux (2002)	1997-1998	Belgium	9,14%
Zitouni et al. (2004)	1998	Walloon Brabant	9,20%

5 The UrbanSim sub-models: price model and location choice models

5.1 Real Estate Price Model

The real estate price model (REPM) used in the Brussels application of UrbanSim is a semi-log linear regression based on Ordinary Least Squares (Franklin & Waddell 2003, Waddell & Ulfarsson 2003). It predicts the average value per dwelling unit, for every year of the simulation.

The results for the REPM are shown in Table 5. Two submodels were estimated: one for the houses (detached, semi-detached and attached), and one for the apartments. There were no available observations of non-residential real estate prices, and therefore no model was estimated for this case.

The price of houses and apartments is positively affected by the car accessibility of the zone and the percentage of green areas in the municipality. Sociodemographic characteristics that have a positive impact are the percentage of households with high income in the municipality, and the logarithm of the population density.

In order to reduce potential endogeneity issues, an instrument variable (De Palma & Picard 2005) was included in this model's specification. This is the municipal income tax, which is the part of the income tax levied by the municipalites, and has a negative effect.

The REPM presented in Table 5 is mostly based on location (neighborhood or municipality) attributes. The only building-specific attribute used is the residential surface, which is positive. Despite the fact that the literature shows that prices are largely explained by attributes of the buildings (Löchl & Axhausen 2010, Efthymiou & Antoniou 2013), the presented models are still able to capture land-use effects that should be relevant for the modeling purposes.

Table 5: Real Estate Price Model

Houses (n=14835)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
constant	-			11.5407	857.94
$\beta_{\text{car-acc}}$	Car accessibility	zone	%	0.0020	4.09
β_{green}	Green area score	commune	0 to 1	0.1349	10.81
$\beta_{\text{income-high}}$	Percentage of high income (>3) households	commune	%	0.0260	60.02
β_{tax}	Housing tax	commune	%	-0.0681	-47.75
$\beta_{\text{pop-den}}$	Logarithm of population density	commune	ln(pop/hectare)	0.0591	56.33
β_{sqm}	Surface	building	m^2	0.0005	8.751
$\boldsymbol{R}^2$=0.59					

Apartments (n=4945)					
Name	**Definition**	**Level**	**Unit**	**Coefficient**	**t-value**
constant	-			11.2914	368.69
$\beta_{\text{car-acc}}$	Car accessibility	zone	%	0.0046	4.09
β_{green}	Green area score	commune	0 to 1	0.4128	14.24
$\beta_{\text{income-high}}$	Percentage of high income (>3) households	commune	%	0.0225	22.67
β_{tax}	Housing tax	commune	%	-0.0334	-10.13
$\beta_{\text{pop-den}}$	Logarithm of population density	zone	ln(pop/hectare)	0.0020	1.82
β_{sqm}	Surface	building	m^2	0.0002	1.89
$\boldsymbol{R}^2$=0.31					

5.2 Household Location Choice Model

The Household Location Choice Model (HLCM) estimation results are presented in Table 6. As the other location choice models, the HLCM predicts the probability that an agent chooses a zone (statistical sector) as a location.

All parameters are statistically significant and have the expected signs. Price has a negative effect in the utility for all households, no matter their income level. The presence of high income households attracts other households of high income but makes locations less affordable for low income households. Households with university degree holders prefer to be located in zones with high ratio of university degree holders. This is consistent with the expected social agglomeration and segregation effects usually observed in residential location.

Car accessibility increases the utility of car-owning households. Households with workers prefer to be located closer to the central business districts while households not owning any cars select locations close to the rail stations. Municipalities with high percentage of green areas are more attractive.

The spatial alternative-specific constant that accounts for unobserved attributes, indicates the attractiveness of the central locations. This constant is active when the location is inside the BCR.

5.3 Employment Location Choice Model

The Employment Location Choice Model (ELCM) is subdivided in eight sub-models, one for each type of economic activity. Table 7 shows the estimation results for each submodel. Jobs in the agricultural and mining sectors are not considered for modelling purposes, because of their low share overall jobs.

Employment location choice of each sector is positively affected by the density of jobs of the same sector in the municipality. The logarithm of non-residential surface and the car accessibility in zone, have a positive impact, when significant. The results for the industry jobs location sub-model shows that there is a negative effect of the density of jobs in the zone, which is only the case in this particular sub-model. Office jobs prefer to locate in zones with agglomeration economies and therefore favor density of jobs of the same type. Job density also has a positive effect in the utility for office jobs, probably because office jobs are service providers and prefer to locate near potential clients. Retail jobs also have benefits from the agglomeration economies and therefore the presence of jobs of the same type and of jobs in general have a positive effect in their location preferences. Finally, it is noted that health and leisure activities prefer to be located in municipalities with high percentage of high income households.

Table 6: Household Location Choice Model

(n=48526)

Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{car-access}}$	Households with car * Car accessibility	household * zone	0 or 1 * (logsum)	0.0106	2.95
β_{educ}	Household with high education level * Ratio of university degree holders in zone	household * zone	0 or 1 * ratio	3.6401	27.97
β_{green}	Green area score	commune	0 to 1	0.1924	2.62
$\beta_{\text{income-low}}$	Households at income class 1 or 2 * Ratio of hh with high income over all hh	household * zone	0 or 1 * ratio	-2.8948	-13.12
$\beta_{\text{income-high}}$	Households at income class 4 or 5 * Ratio of hh with high income over all hh	household * zone	0 or 1 * ratio	4.8074	12.95
β_{workers}	Households with workers * Log distance from CBD	household * zone	0 or 1 * ln(meters)	-0.1453	-12.44
β_{rail}	Households without cars * Distance from rail station $<$1000m	household * zone	0 or 1 * meters	0.3681	12.82
β_{price}	Logarithm of transaction price	building	log(euros)	-1.0298	-29.09
ASC_{BCR}	Central Brussels area (central communes)	commune	0 or 1	0.8738	44.64
Log-likelihood=–95751					

Table 7: Employment Location Choice Model

Name	Definition	Level	Specification	Coefficient	t-value
Industry (n=13943)					
$\beta_{\text{job-den}}$	Logarithm of job density	zone	ln(jobs/hectare)	-0.0627	-7.43
β_{sam}	Logarithm of non residential surface	building	$\ln(m^2)$	1.2514	118.65
$\beta_{\text{ind-den}}$	Density of jobs in industry sector	commune	jobs/hectare	0.0782	27.47
Log-likelihood=-13634					
Office (n=14937)					
$\beta_{\text{gov-den}}$	Density of jobs in public sector	commune	jobs/hectare	-0.0212	-6.36
$\beta_{\text{off-den}}$	Density of jobs in private sector (office)	commune	jobs/hectare	0.0152	4.93
$\beta_{\text{job-den}}$	Logarithm of job density	zone	ln(jobs/hectare)	0.6641	70.19
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	-0.0057	-12.08
β_{sqm}	Logarithm of non residential surface	building	$\ln(m^2)$	0.5227	72.36
Log-likelihood=-22791					
Retail (n=3886)					
$\beta_{\text{car-access}}$	Car accessibility	zone	logsum	0.0384	3.50
$\beta_{\text{ret-den}}$	Density of jobs in retail sector	commune	jobs/hectare	0.1643	4.43
$\beta_{\text{job-den}}$	Logarithm of job density	zone	ln(jobs/hectare)	0.0780	5.09
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	-0.0036	-2.19
β_{sqm}	Logarithm of non residential surface	building	$\ln(m^2)$	0.8906	51.24
Log-likelihood=-6443					
Hotels/Bar/Restaurants (n=2013)					
$\beta_{\text{car-access}}$	Car accessibility	zone	logsum	0.0427	3.21
$\beta_{\text{job-den}}$	Logarithm of job density	zone	ln(jobs/hectare)	0.3854	22.82
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	-0.0076	-7.10
β_{sqm}	Logarithm of non residential surface	building	$\ln(m^2)$	0.3377	23.73
$\beta_{\text{hbr-den}}$	Density of jobs in hotels/bar/restaurants	commune	jobs/hectare	0.2018	10.44
Log-likelihood=-4923					
Government and public service (n=8471)					
$\beta_{\text{off-den}}$	Density of jobs in private sector	commune	jobs/hectare	0.0125	6.69
$\beta_{\text{job-den}}$	Logarithm of job density	zone	ln(jobs/hectare)	0.7523	58.37
$\beta_{\text{pop-den}}$	Logarithm of population density	commune	ln(pop/hectare)	-0.0045	-7.69
β_{sqm}	Logarithm of non residential surface	building	$\ln(m^2)$	0.5081	44.25
Log-likelihood=-10973					
Education (n=3775)					
$\beta_{\text{edu-den}}$	Density of jobs in education sector	commune	jobs/hectare	0.2208	14.08
$\beta_{\text{job-den}}$	Logarithm of job density	zone	ln(jobs/hectare)	0.1824	11.37
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	-0.0075	-7.65
β_{sqm}	Logarithm of non residential surface	building	$\ln(m^2)$	0.8405	46.04
Log-likelihood=-5995					
Health (n=5099)					
$\beta_{\text{high-inc}}$	Percentage of households in high income scale (>3)	commune	%	0.0564	9.86
$\beta_{\text{hea-den}}$	Density of jobs in health sector	commune	jobs/hectare	0.1832	17.10
$\beta_{\text{job-den}}$	Logarithm of job density	zone	ln(jobs/hectare)	0.3708	32.00
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	-0.0129	-13.04
β_{sqm}	Logarithm of non residential surface	building	$\ln(m^2)$	0.4908	41.29
Log-likelihood=-10493					
Leisure activities (n=1315)					
$\beta_{\text{high-inc}}$	Percentage of households in high income scale (>3)	commune	%	0.0837	6.58
$\beta_{\text{leiz-den}}$	Density of jobs in leisure sector	commune	jobs/hectare	0.2978	16.43
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	0.0133	11.17
β_{sqm}	Logarithm of non residential surface	building	$\ln(m^2)$	0.6327	27.56
Log-likelihood=-2349					

5.4 Residential Development Project Location Choice Model

Estimation results for the Residential Development Location Choice Model (RDPLCM) are presented in Table 8. The models are estimated over data for real estate developments that took place in the ten year period previous to the base year and, therefore, are not representative of all existing supply in the city. All types of residential development tend to agglomerate and therefore have a positive parameter for the logarithm of the number of buildings of the same type. The dwelling categories "semi-detached" and "attached" were grouped for the purpose of this research, because of their similar characteristics.

Residential buildings are developed preferentially in zones with a higher price of residential units. The population density of the municipality has a positive impact for semi-detached, attached and apartments, but is insignificant for detached houses.

5.5 Non-Residential Development Project Location Choice Model

The Non-Residential Development Project Location Choice Model (NRDPLCM) models the location of the developed non-residential projects. Eight sub-models were estimated in UrbanSim, one for each of the building types: 1) industrial, 2) office, 3) shops, 4) hotels/bar/restaurants, 5) government and public service, 6) education, 7) health, 8) leisure activities. Since there were not a significant number of development projects in the past, sub-models regarding quarrying and agricultural buildings were not estimated.

The estimation results are shown in Table 9. New non-residential supply tends to locate in places that already show agglomeration and with high concentration of other activities in general.

Development of building projects that host private services is negatively affected by the population density of the municipality and the logarithm of the total population in the zone, and positively by the logarithm of total number of jobs in zone. Another factor that affects the development of retail buildings is the number of jobs in the zone. The more jobs, the more preferable the zone is for the development of such infrastructure. The number of citizens in a zone is a positive determinant of the location.

5.6 Workplace Choice Model for Residents

The Workplace Choice Model for Residents (WCMR) assigns jobs to workers of the households. For its estimation, a table with information about the household and job of each person at the base year was created. The model contains two variables: the car accessibility per zone, whose coefficient is positive, and the distance between the house and work location of the person, whose coefficient is negative.

Table 8: Residential Development Project Location Choice Model

Detached (n=59558)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
β_{price}	Logarithm of price of detached houses	building	ln(euros)	1.5334	59.31
β_{units}	Logarithm of number of detached house units	building	ln(sum)	1.6578	338.21
Log-likelihood=-160082					

Semi-detached and Attached (n=20119)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
β_{price}	Logarithm of price of semi-detached and attached houses	building	ln(euros)	0.3013	7.06
β_{units}	Logarithm of number of semi-detached and attached house units	building	ln(sum)	1.1172	164.97
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	0.4097	37.48
Log-likelihood=-58729					

Apartments (n=5119)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
β_{price}	Logarithm price of apartments	building	ln(euros)	0.1823	2.38
β_{units}	Logarithm of number of apartment units	building	ln(sum)	0.1823	2.38
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	1.0609	85.62
Log-likelihood=-12286					

Table 9: Non-Residential Development Project Location Choice Model

Industry (n=2770)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{car-access}}$	Car accessibility	zone	logsum	-0.0659	-6.25
$\beta_{\text{ind-den}}$	Density of jobs in industrial sector	commune	jobs/hectare	-0.0705	-10.32
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	0.4251	33.19
Log-likelihood=-10949					
Office (private sector) (n=767)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{car-access}}$	Car accessibility	zone	logsum	0.0906	3.61
$\beta_{\text{off-den}}$	Density of jobs in private sector	commune	jobs/hectare	0.0269	3.32
$\beta_{\text{pop-den}}$	Population density	commune	pop/acre	-0.0318	-5.86
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	1.1741	34.43
$\beta_{\text{ln-pop-zone}}$	Logarithm of total number of population	zone	ln(sum)	-0.1460	-5.30
Log-likelihood=-1953					
Shops (n=1466)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	0.4451	21.84
$\beta_{\text{ln-pop-zone}}$	Logarithm of total number of population	zone	ln(sum)	0.3899	12.62
Log-likelihood=-5451					
Hotels, bar, restaurants (n=107)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{car-access}}$	Car accessibility	zone	logsum	0.2219	2.73
$\beta_{\text{hbr-den}}$	Density of jobs in hotels/bar/restaurants	commune	jobs/hectare	0.1600	1.56
$\beta_{\text{pop-den}}$	Population density	commune	pop/hectare	-0.0365	-2.89
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	0.7093	8.81
Log-likelihood=-359					
Government and public service (n=264)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	0.7184	15.57
$\beta_{\text{ln-pop-zone}}$	Logarithm of total number of population	zone	ln(sum)	0.1059	2.24
Log-likelihood=-932					
Education (n=140)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	0.3591	6.21
$\beta_{\text{ln-pop-zone}}$	Logarithm of total number of population	zone	ln(sum)	0.3539	5.77
Log-likelihood=-533					
Health (n=225)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	0.3523	5.45
$\beta_{\text{ln-pop-zone}}$	Logarithm of total number of population	zone	ln(sum)	0.5394	7.55
Log-likelihood=-840					
Leisure activities (n=970)					
Name	**Definition**	**Level**	**Specification**	**Coefficient**	**t-value**
$\beta_{\text{car-access}}$	Car accessibility	zone	logsum	-0.0240	-1.70
$\beta_{\text{lei-den}}$	Density of jobs in leisure sector	commune	jobs/hectare	3.2041	8.41
$\beta_{\text{ln-jobs-zone}}$	Logarithm of total number of jobs	zone	ln(sum)	0.2371	11.14
Log-likelihood=-3867					

6 The MATSim model for Brussels

The MATSim model is described in detail in Chapter 3.2?. The main principles are summarized here and the model specifications for the Brussels case study are described.

MATSim is a microscopic ("agent-based") traffic simulation model. Every single part of the traffic system – e.g. a synthetic traveller – is simulated separately and is represented by a so-called agent. These agents typically have at least one full daily plan, each containing desired activities and desired transport modes. All agents compete for system-resources, e.g. the flow capacity of a street (Balmer et al. 2009).

When UrbanSim moves forward in time from year to year, it calls MATSim in regular intervals to generate the traffic assignment and update the accessibility of the zones and the travel indicators of the persons (travel time and chosen mode), that are used in the next iteration as input for the UrbanSim sub-models (see Chapter 3.2?).

Besides the road traffic model, a mode choice model was implemented within MATSim. In this model, agents are allowed to choose between car, public transport and walk.

As for the simulation of public transport, there are several variants of how the generalized cost between public transit stops can be calculated (see Chapter 3.2?). For the Brussels case study, travel times and distances for each pair of public transport stops were provided as inputs. Agents that plan to use the public transport are forced to walk to the next stop. During the simulations of the integrated UrbanSim-MATSim model, there is no process that updates the public transport travel times. Moreover, the defined scenarios (see Section 8) are not scenarios of public transport policies, which means that the public transport supply is the same as in the reference scenario assuming business-as-usual.

Travel times for agents walking were calculated with the beeline distance and an average speed of 1 m/s. The mode walk was allowed in the simulations because the density of the street network in the model is very low, even in the center. Allowing the mode walk gives the agents a chance to reach nearby activity locations by a short beeline walk rather than by a much longer trip on the network.

The relevant part of the MATSim mode choice utility function reads, in linearized form,

$$U_{\text{mode}} = Const_{\text{mode}} + \beta_{\text{money}} \cdot \text{money} + (\beta_{\text{ttime,mode}} - \beta_{\text{perf}}) \cdot \text{ttime}_{\text{mode}} \quad (1)$$

where $Const_{\text{mode}}$ is the mode constant;

β_{money} is the marginal utility of money;

$\beta_{\text{ttime,mode}}$ is the marginal utility of spending time traveling by mode;

β_{perf} is the marginal opportunity cost of time.

The marginal utility of money and time were set in order to get a value of time equal to 9€2001/h (inspired from Stratec (2006)). The alternative specific constant for the public transport, $Const_{pt}$, describes the inhibition threshold to use public transport. During the calibration process, a certain number of experiments, varying this parameter between -4 and -1, was done. -1 was found to deliver the closest results to the modal shares from the IRIS 2 model (Röder et al. 2013).

Note that the mode choice model, as, in fact, all choice models in MATSim, is slightly different from the "classical" logit mode choice models in the sense that it includes a learning process: in MATSim, the travellers select transport options (modes and paths), try them out and compute a utility based on the performance of the options. Subsequently, they choose between the options that they have tested, based on a logit model.

7 Reconstitution of the base year 2001 and of the year 2007

Comparing the situation simulated by the model with the observed situation provides an indication of the model strengths and weaknesses in predicting the real socio-economic (population and employment) and transport (mode shares and travel times) situation. The first task of the model is to reconstitute as far as possible the observed 2001 situation. The reconstitution of the year 2007 by the model was also analyzed.

The validation process is based on a baseline scenario. The time interval for the simulation was set to 5 years for MATSim. A 5% sample of the agents that make trips to work was randomly drawn by MATSim. This sample size was used for all the simulations in order to speed up the computation and avoid memory limitation issues. 5%, and in fact even 1%, has been found sufficient in previous studies to obtain plausible congestion patterns (Nagel 2008, 2011), at least as long as no schedule-based public transit is included (Neumann et al. 2012). Clearly, larger sample sizes produce fewer fluctuations between runs and thus smaller statistical errors, e.g. for zone-to-zone travel times.

The ability of a model to reproduce the observed situation can be assessed on the basis of a comparison between the predicted and observed values. Here the comparison was done at the municipal level.

Figure 3 and Figure 4 show the efficiency of the model in reconstituting with considerable accuracy the observed population (R^2 = 0.997) and employment (R^2 = 0.997) for the year 2001.

Figure 5 and Figure 6 show that the model also predicts with great accuracy the observed population (R^2 = 0.972) and employment (R^2 = 0.921) for the year 2007.

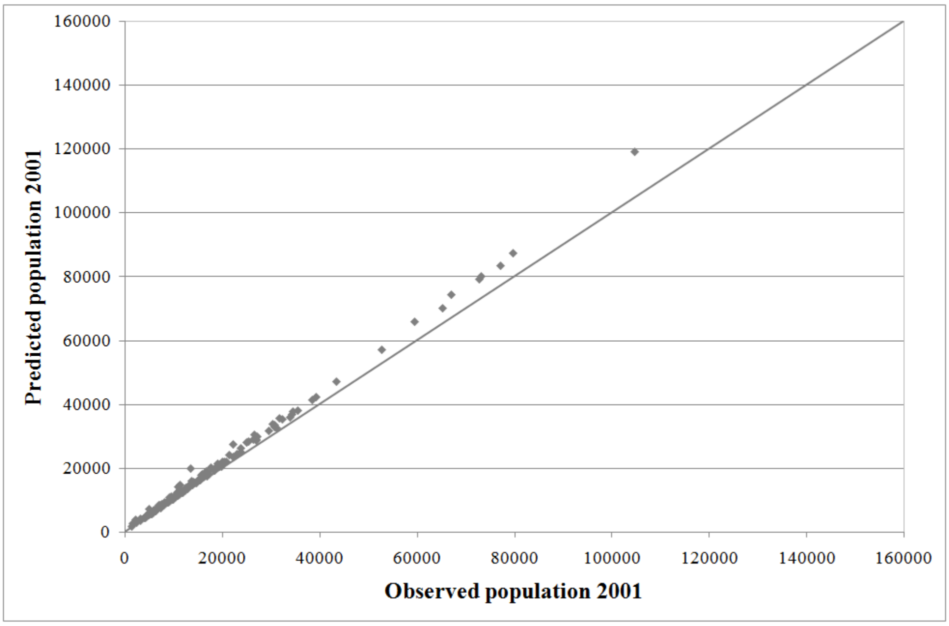

Figure 3: Comparison between predicted and observed population in year 2001. The grey line is the 1:1 line.

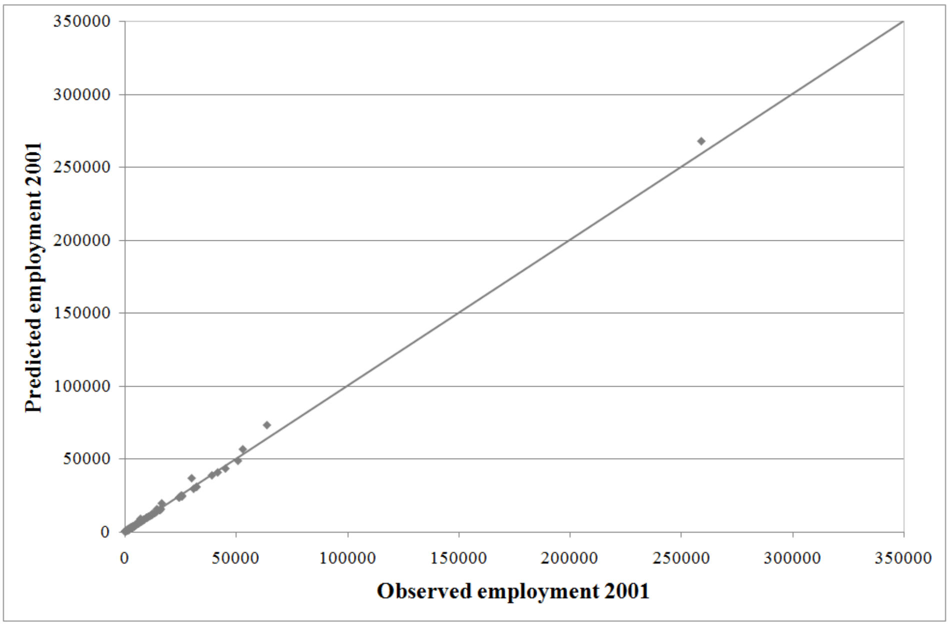

Figure 4: Comparison between predicted and employment in year 2001. The grey line is the 1:1 line.

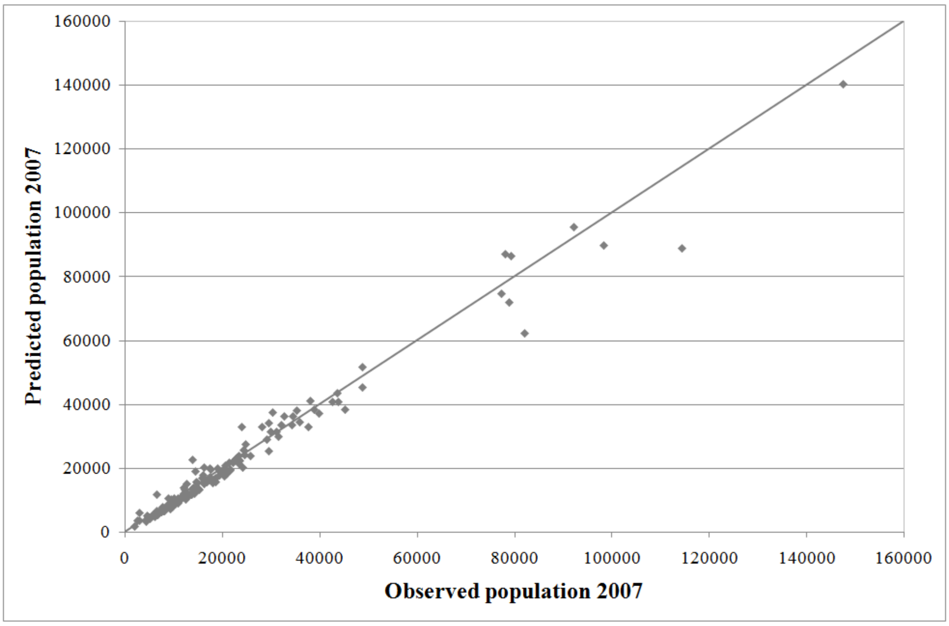

Figure 5: Comparison between predicted and observed population in year 2007. The grey line is the 1:1 line.

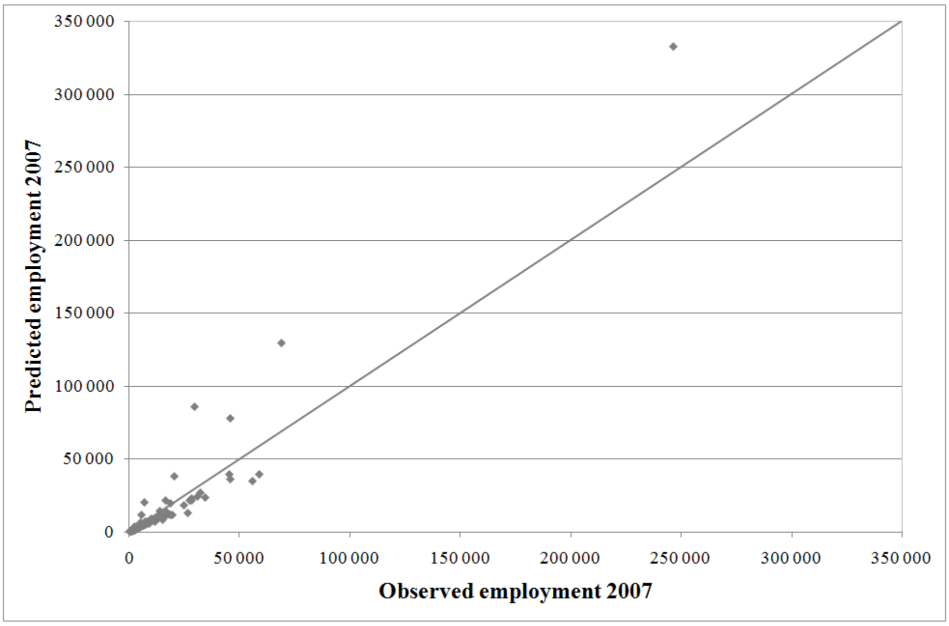

Figure 6: Comparison between predicted and observed employment in year 2007. The grey line is the 1:1 line.

The dispersion around the 1:1 line indicates that the model predicts population and employment with less accuracy in 2007 than in 2001. The reconstitution of 2007 is interesting as a check but we should not expect the model to reconstitute perfectly the observed evolution 2001-2007, because in the model one puts as variables only the features that one want to change (as a policy variable), all other being fixed. In other words, the objective and utility of these models is to simulate and evaluate policies in a given reference framework, not to forecast the future.

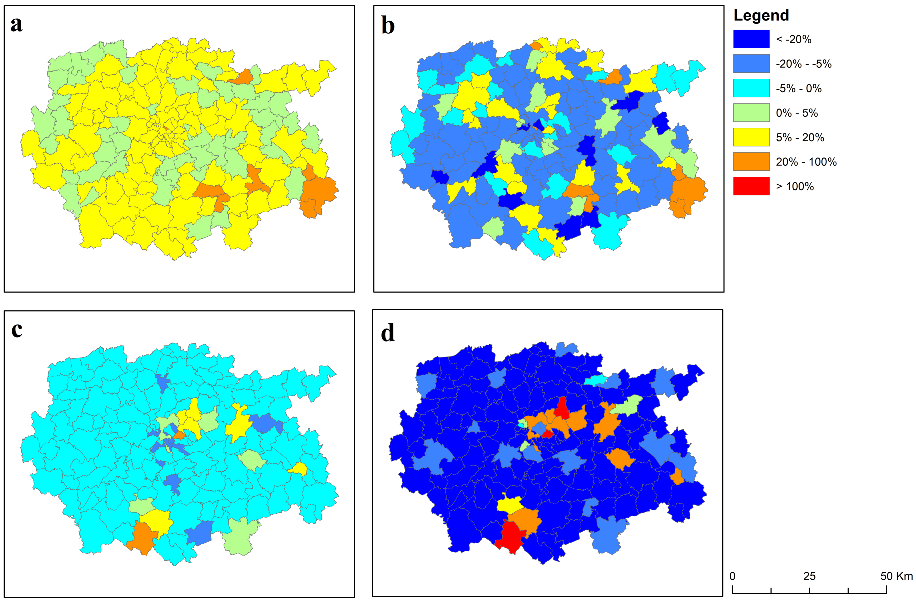

Figure 7: Relative differences between the predicted and observed values : population 2001 (a), population 2007 (b), employment 2001 (c) and employment 2007 (d).

The figures of the relative differences between observed and modelled values per municipality (Figure 7) give a more nuanced picture.

We conclude that the year 2001 is better predicted than the year 2007 and that population is better predicted than employment.

As for the reconstitution of the transport situation, the 2001 car travel times and car shares predicted by MATSim per macrozone for the morning peak hours (6 am - 10 am) were compared with the car travel times and car shares from the IRIS 2 model.

The modelled average morning travel times by car were found to be higher compared to the values of the IRIS 2 model, which is due to the fact that the model was only partially calibrated. However tendencies are correct: trips heading towards the city center are significantly longer (in time) than trips heading towards the outside zones.

As shown in Table 10, the car shares predicted by MATSim are close to the IRIS 2 reference data. A clear tendency is noticeable: trips leaving the city center are mainly performed by car and trips heading towards the center are more often performed by another mode. Within a zone, the MATSim model clearly underestimates the car share, this results from the opportunity for the agents to walk (short trips are more often performed by foot) (Röder et al. 2013).

Note that a meaningful analysis for trips from and to macrozone 7 is not possible as the number of trips predicted by the model is very low. Indeed, this zone extends further than the study area of the Brussels case study. Other entries with small number of trips were also removed from the comparison. The reason why the model gives such low numbers is that MATSim simulations were run with a 5% sample of the population.

It must also be reminded that two models very different in their specifications are here compared and that the MATSim model is not calibrated as far as it would have been desirable, while the IRIS 2 model is a fully validated model against observed data.

8 Definition of the scenarios

The following policies were simulated: the reference scenario assuming business-as-usual (BAU), the cordon pricing scenario and the densification scenario. The latter scenarios are further detailed below.

The scenarios were simulated from 2001 to 2020. The time interval for each simulation was set to 1 year for UrbanSim and 5 years for MATSim in order to update the accessibility values of zones and the travel related indicators of persons (i.e. chosen mode and travel time). Generally, land-use changes occur at a slower rate than changes in choices related to commuting (i.e. mode choice and route choice) (Wegener 2007). However, the time intervals were imposed by technical constraints: the time interval of UrbanSim is set to 1 year by default; the time interval of MATSim could have been set to 1 year but the computations times would have been much higher. The results of each scenario are based on the average values from 4 simulation runs. The comparison of the runs revealed that the inter-run variation can be up to 1%.

8.1 Cordon pricing scenario

The cordon is located just outside the Ring road (orbital highway) which surrounds the BCR and some adjacent municipalities (Figure 8). It was decided to include the

Table 10: Comparison between the car shares from the IRIS 2 model and from the MATSim model per origin-destination relation at the macrozone level between 6 am and 10 am.

Car shares from the IRIS 2 model							
	1	2	3	4	5	6	7
1	44%	69%	54%	75%	84%	48%	67%
2	43%	60%	66%	76%	73%	69%	82%
3	28%	67%	67%	78%	73%	72%	87%
4	24%	65%	78%	77%	82%	86%	95%
5	26%	67%	79%	89%	83%	83%	95%
6	22%	59%	78%	94%	91%	84%	85%
7	29%	59%	75%	96%	96%	86%	85%

Car shares from the MATSim model							
	1	2	3	4	5	6	7
1		64%	75%				
2	36%	44%	67%	85%	78%	81%	
3	34%	43%	61%	82%	86%	82%	
4	28%	47%	69%	75%	87%	86%	
5	20%	34%	62%	83%	81%	85%	
6	14%	23%	43%	67%	80%	85%	
7							

Differences							
	1	2	3	4	5	6	7
1		-5%	21%				
2	-7%	-16%	1%	9%	5%	12%	
3	6%	-24%	-6%	4%	13%	10%	
4	4%	-18%	-9%	-2%	5%	0%	
5	-6%	-33%	-17%	-6%	-2%	2%	
6	-8%	-36%	-35%	-27%	-11%	1%	
7							

Ring road inside the cordon as it is also affected by congestion. Also, on a more practical side, setting the limits of the cordon to the Ring road reduces the number of entries/exits and allows for easier controls. Every car entering the area inside the cordon during the morning peak period (i.e. between 6 am and 10 am) has to pay an additional cost of 5€. The cordon was here implemented at the end of the year 2001 in order to see the long-term effects on households and jobs relocation. Preliminary tests with the cordon implemented in 2015 had shown small effects on agents relocation.

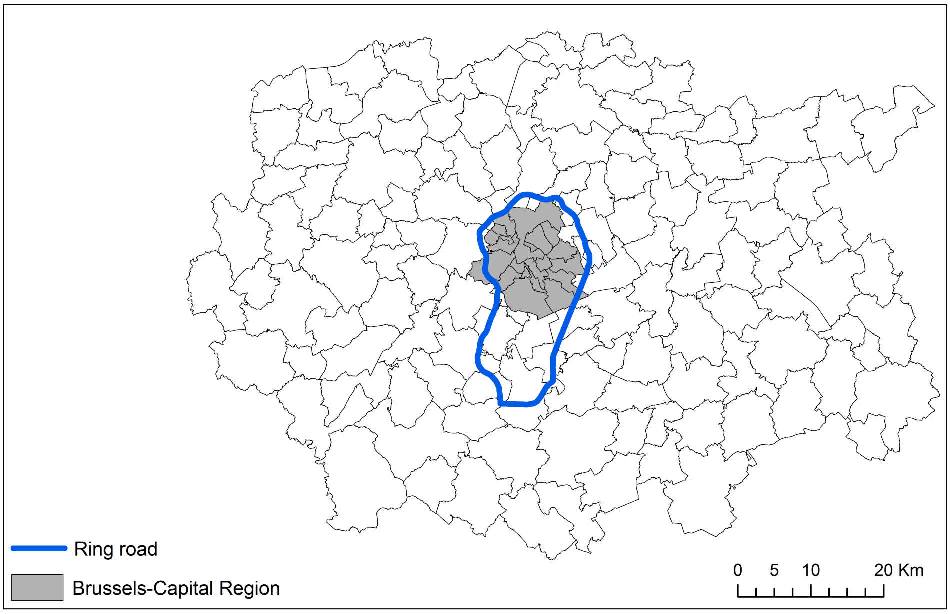

Figure 8: Cordon pricing scenario zone located in the Brussels study area

8.2 Densification scenario

The objective of this scenario was to test the effects of household and job densification in zones defined as having a high accessibility by public transport. The definition of the highly accessible zones is different for the population densification and for the job densification.

8.2.1 Population densification

The population densifications scenario was implemented by increasing the housing supply in zones having a high accessibility by public transport. These zones highly accessible were located in the municipalities belonging to the "operational agglomeration" as defined by Van Hecke et al. (2009)[4]. The "operational agglomeration" is formed by the 36 municipalities classified as the "center" and the "agglomeration" (Figure 9). Note that this area is actually composed of 41 communes but 5 of them were excluded as they belong to the urban area of Leuven, Mechelen and Antwerp.

The increase in housing supply was spread over time from 2013 to 2017 (i.e. 5 years). During this period, the number of residential units was increased each year by 2% in the BCR and by 4% in the other municipalities of the operational

[4]A municipality belongs to the operational agglomeration if more than 50% of its population lives in the morphological agglomeration. The definition of the morphological agglomeration is based on the inter-building distances (minimum 200 meters).

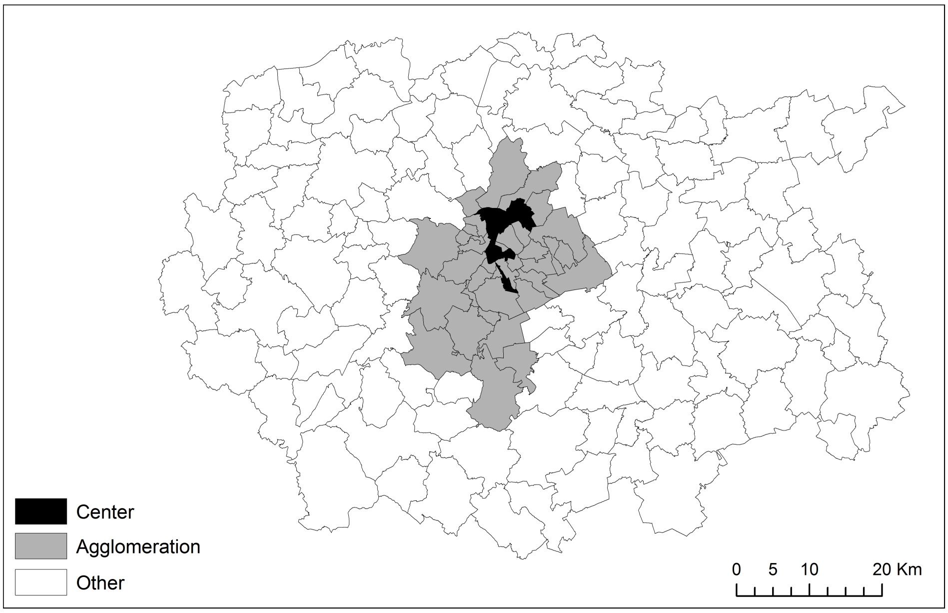

Figure 9: Target areas for population densification (center + agglomeration) in the densification scenario.

agglomeration compared to the existing residential units at the end of the previous year [5].

8.2.2 Job densification

It was decided to focus the job densification on the tertiary sector and to implement the scenario by increasing the available office floor space located in zones having a high accessibility by public transport. This policy was inspired from the “ABC policy”, which was created in The Netherlands, about 25 years ago. The ABC policy aims to the best possible adequacy between *the mobility needs of enterprises and the accessibility profiles of locations*: it could be summarized as “The right business at the right place”. In the general definition of this policy, the A locations are highly accessible by public transport (e.g. served by an inter-regional/inter-city railway station), the C locations have a car-oriented accessibility (e.g. near to a highway exit/entrance), the B locations lie somewhere in-between the A and C situations (medium-level accessibility both by public transport and by car). Eventually, the remaining locations classified as “R locations” offer a poor accessibility both

[5]Note that the 2% increase per year on the period 2013-2017 for the BCR (i.e. a total increase by about 50 000 units) is not far from what is currently discussed by politicians: indeed the Region will have to face an important demographic growth in the coming decade, which would require an increase of the housing supply by about 100 000 units by 2020.

by public transport and by car. As far as the enterprises are concerned, the A profile corresponds to a high concentration of employment (i.e. high number of jobs per floor space unit), a large number of visitors, and activity sectors not highly depending from the road (e.g. no road freight). The C profile, on the opposite side, is characterized by a low concentration of employment, a small number of visitors, and a high dependence on road accessibility. The B profile is characterized by a medium-level concentration of employment, a moderate number of visitors and a moderate dependency on road. As examples, the A profile includes the large private sector offices and public administrations, the C profile includes the wholesale distribution centres, the B profile includes department stores and retail shops (Martens & Griethuysen 1999, Fontaine 2010).

In the Brussels case study, the A, B, C, R accessibility profiles of the statistical sectors were defined as follows:

- profile A : statistical sectors whose centroid is less than 1200 meters from an inter-regional/inter-city railway station;
- profile B : statistical sectors whose centroid is less than 800 meters from a RER station and within 2000 meters of a highway entrance/exit (excluding profile A);
- profile C : statistical sectors whose centroid is within 2000 meters of a highway entrance/exit (excluding profile A or B);
- profile R : all other statistical sectors.

Figure 10 shows the distribution of the zones in the study area.

The increase in the office floor space was set to 20% of the increase observed between 2001 and 2020 in the BAU scenario. The densification was split between statistical sectors classified as A and B, proportionally to the available floor space capacity of office buildings (i.e. developable office floor space). Densification was spread over time from 2013 to 2017, which means that 20% of the total increase in floor space of a particular building is built each year.

The population and job densification scenarios were defined with a concern for realism. For this reason, densification was spread over time and the assumption for increasing housing supplies was stronger than the one for increasing office floor spaces. Indeed, in the Brussels context, it is easier to increase housing supplies (e.g. by the conversion of single-family buildings into multiple units).

9 Simulation results

Each scenario was simulated from 2001 to 2020 and the results were compared with the business-as-usual (BAU) scenario.

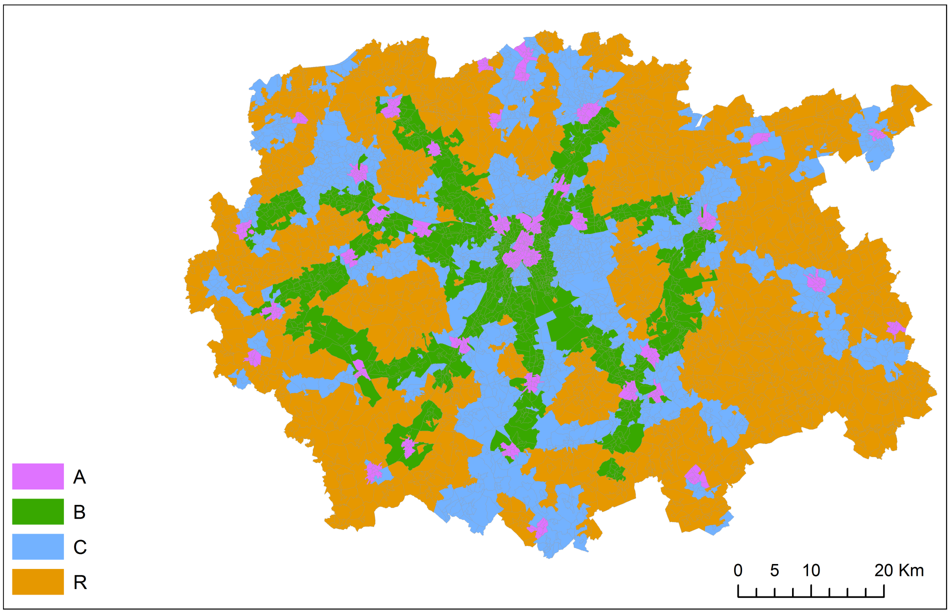

Figure 10: “ABC” typology of the statistical sectors of the study area.

Both land use and transport indicators were computed. The key indicators used to assess the effect of the policies were as follows:

- number of households in the Brussels-Capital Region;
- number of households located inside the cordon (for the cordon pricing scenario);
- number of households located inside the target area for densification (for the densification scenario);
- number of jobs in the Brussels-Capital Region;
- number of jobs located inside the cordon (for the cordon pricing scenario);
- number of jobs located inside the target area for densification (for the densification scenario);
- average car shares for the all day and in the morning peak hours, for the whole study area and the Brussels-Capital Region (trips travelled inside the Region);
- average travel times (all modes together and by car);
- average home-work travel distance;

The indicator values for the different scenarios are given in Table 11.

Table 11: Land-use and transport indicators for the Brussels case study

		Base year *in comparison*	**BAU** *Base year*	**Cordon** *BAU*	**Densification** *BAU*
Land-Use Indicators					
Number of households in Brussels-Capital Region	number of households	411 047	459 214	458 718	498 123
Absolute variation			*48 167*	*-496*	*38 909*
Relative variation	%		*11.7%*	*-0.1%*	*8.5%*
Number of households inside the cordon	number of households	467 794	520 485	520 405	/
Absolute variation			*52 691*	*-80*	/
Relative variation	%		*11.3%*	*0.0%*	/
Number of households in the target area of densification	number of households	563 411	644 214	/	707 180
Absolute variation			*80 803*	/	*62 966*
Relative variation	%		*14.3%*	/	*9.8%*
Number of jobs in Brussels-Capital Region	number of jobs	678 251	871 142	873 919	865 326
Absolute variation			*192 891*	*2 778*	*-5 816*
Relative variation	%		*28.4%*	*0.3%*	*-0.7%*
Number of jobs inside the cordon	number of jobs	732 560	944 533	947 247	/
Absolute variation			*211 974*	*2 714*	/
Relative variation	%		*28.9%*	*0.3%*	/
Number of jobs in the target area of densification	number of jobs	905 542	1 138 070	/	1 133 418
Absolute variation			*232 528*	/	*-4 652*
Relative variation	%		*25.7%*	/	*-0.4%*
Transport Indicators					
Average modal share of car, in the study area	%, all day	73.6%	67.5%	66.4%	67.6%
Absolute variation	*points*		*-0.1*	*-1.0*	*0.1*
Relative variation	%		*-8%*	*-1.5%*	*0.2%*
Average modal share of car, in Brussels-Capital Region	%, all day	60.2%	53.7%	54.0%	54.0%
Absolute variation	*points*		*-0.1*	*0.4*	*0.4*
Relative variation	%		*-11%*	*0.7%*	*0.7%*
Average modal share of car, in the study area	%, on the morning peak hours (6 am-10 am)	72.0%	65.2%	64.2%	65.4%
Absolute variation	*points*		*-0.1*	*-1.0*	*0.2*
Relative variation	%		*-9.5%*	*-1.5%*	*0.3%*
Average modal share of car, in Brussels-Capital Region	%, on the morning peak hours (6 am-10 am)	57.6%	50.9%	51.3%	51.1%
Absolute variation	*points*		*-0.1*	*0.4*	*0.2*
Relative variation	%		*-12%*	*0.8%*	*0.4%*
Average travel time (all modes), in the study area	minutes, all day	58.1	62.2	60.3	62.1
Absolute variation			*4.1*	*-1.9*	*-0.1*
Relative variation	%		*7.1%*	*-3.1%*	*-0.2%*
Average travel time for car trips, in the study area	minutes, all day	56.8	60.7	57.8	60.6
Absolute variation			*3.8*	*-2.8*	*0.0*
Relative variation	%		*7%*	*-4.7%*	*-0.1%*
Average home-work travel distance for car trips	kilometers, all day	14.2	13.4	13.2	13.4
Absolute variation			*-0.7*	*-0.2*	*0.0*
Relative variation	%		*-5%*	*-1.6%*	*-0.1%*

9.1 Cordon scenario

The main effect of the cordon scenario is noticeable on transport related indicators, i.e. on car shares and car travel times. Table 11 shows that the cordon pricing scenario leads to a decrease of the car share in the study area, compared to the BAU scenario. The decrease in the whole study area is modest (-1%) which can be explained by the fact that the cordon pricing only applies to cars entering the city center. This means that the room left on the network by the incoming commuters may be occupied by persons travelling inside or outside the cordon. In Table 11, we see that the car share increases slightly in the BCR (+0.4%). The analysis by macrozone confirms that the decrease in car share is more important for the incoming commuters: during the morning peak hours, the car share goes from 39.4% in the BAU scenario to 36.3% in the cordon scenario.

There is also a reduction in car travel time and car travel distance. The effects as regards to travel times (by all modes) result mainly from the combination of two effects going in opposite directions: the changes in the average trip distances and the modal shifts between on average faster modes (car) and on average slower modes (public transport and walk). For this reason, the average travel time for car trips decreases more (- 3 minutes) than the average travel time for all modes together (-2 minutes).

Finally, Figure 11 shows the changes in car accessibility between the BAU scenario and the cordon pricing scenario. Car accessibility is computed for each zone by the MATSim model. The calculation is based on the logsum, which is a utility-based measure of accessibility reflecting the economic benefits as the maximum expected utility that someone gains from access to spatially distributed opportunities like work (Geurs & Ritsema van Eck 2001, de Jong et al. 2007) (for more details, see Chapter 3.2?). The red and yellow zones experience a disadvantage due to roadpricing. The greenest areas experience an improvement.

The car accessibility may improve or deteriorate in the cordon scenario depending on the value of the savings of car travel time to the workplaces, compared to the toll. The savings in car travel time in turn depend on the initial level of congestion and the spatial distribution of the workplaces. This may lead to some local effects [6].

Figure 11 shows a clear tendency: almost the whole area within the Ring benefits from the cordon. For areas outside the cordon, accessibility decreases significantly. The zones just outside the cordon experience the most important loss in car accessibility. This is due to the fact that the toll is included in the generalized cost of travel and that even when congestion is reduced, access to facilities behind the cordon now comes with a higher generalized cost than before. In other words, for

[6] Theoretically it also depends on the distribution of the values of time, but in the Brussels model, the value of time is assumed to be 9€2001/hour for all the travelling individuals.

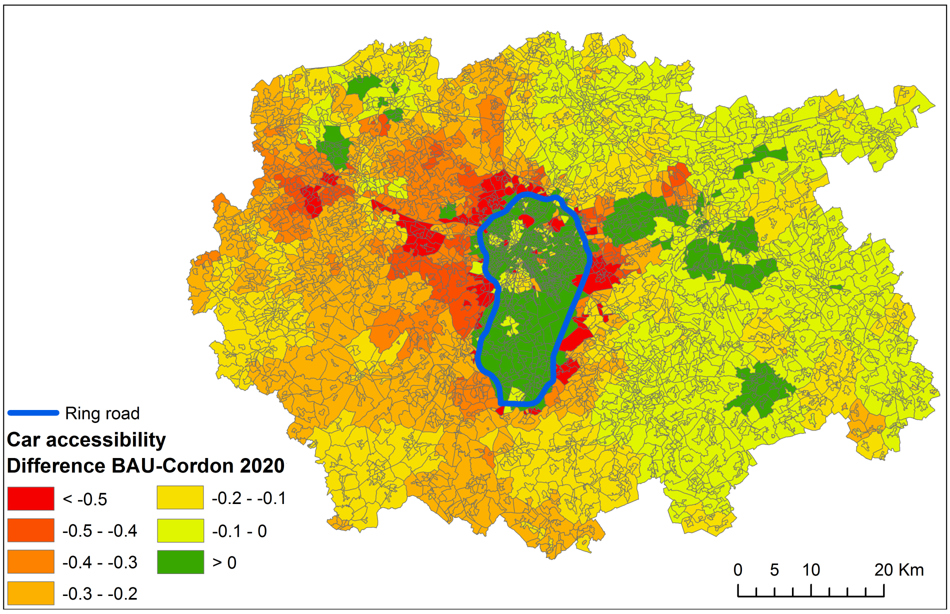

Figure 11: Absolute difference of car accessibility between BAU and cordon pricing scenarios.

these zones, the benefits from the reduction in car travel times and distances do not compensate the increase in monetary costs. Figure 11 also shows that a few zones outside the Ring benefit of an improvement in car accessibility. This may due to local effects (e.g. local reduction of road congestion and therefore better accessibility to the workplaces located outside BCR). Similarly, a few zones inside the Ring undergo a decrease in car accessibility, which is due to the fact that locally the time savings do not compensate the cost due to the toll. Alternatively, the results may also be due to remaining weaknesses in the transport model.

Note that public transport travel times do not vary between the BAU and the cordon scenario. As we saw, the public transport travel times are defined beforehand and are not modelled by MATSim. However, public transport accessibility should change if the spatial distribution of households and jobs change.

Figure 12 and Figure 13 show that the cordon scenario has no significant effect on the location choice of households and jobs.

The land-use indicators in Table 11 show that the relative variation of the number of households or jobs inside the BCR or inside the cordon between the cordon scenario and the BAU scenario, is less or equal to 0.3%, which is actually less than the inter-run variations.

An analysis of the marginal utilities reveals that the car accessibility only influences the location choice of car-owning households and only in a marginal way. A determining factor is the transaction price: the more expensive the real estate good

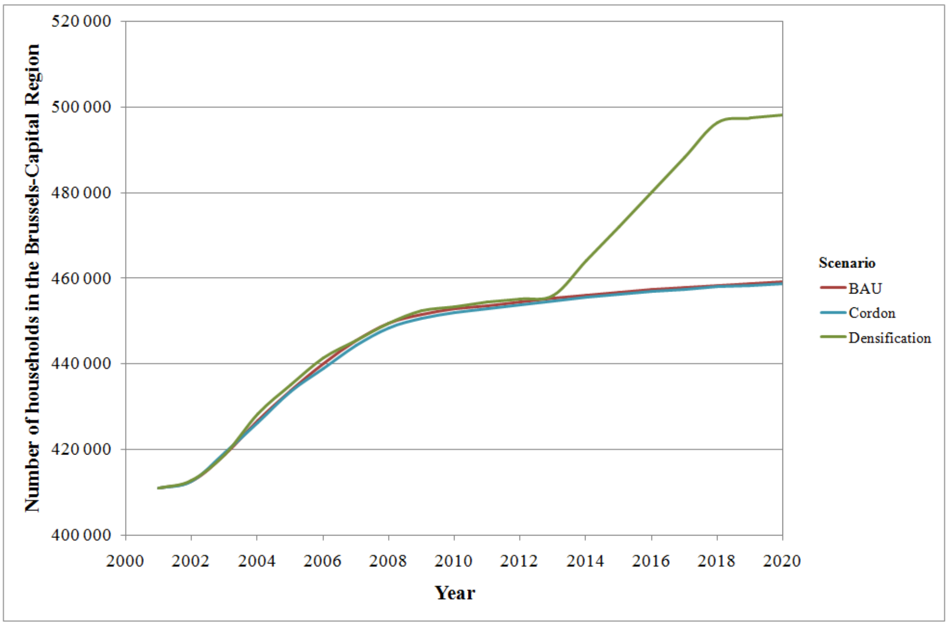

Figure 12: Evolution of the number of households in the Brussels-Capital Region for the three scenarios.

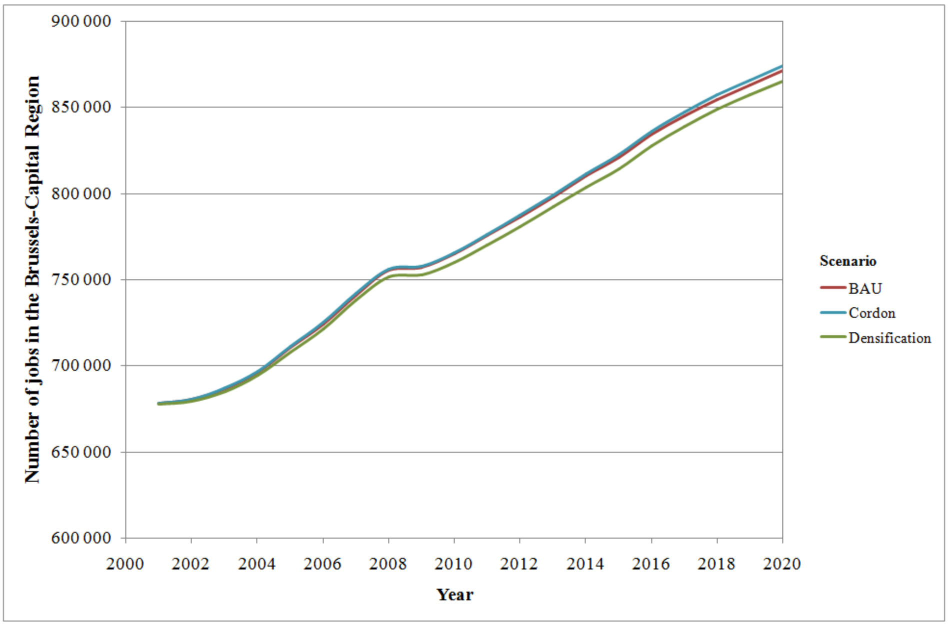

Figure 13: Evolution of the number of jobs in the Brussels-Capital Region for the three scenarios.

is, the less attractive the location will be.

Now looking at the contribution of the different terms of the real estate price model (Table 5), we see that the car accessibility influences positively the real estate price: the more accessible the location is, the more expensive the real estate good will be.

This means there is a kind of “feedback effect”: households want to locate in accessible locations (and still prefer less expensive buildings) but at the same time the price of the buildings increases with the car accessibility.

As for the employment location choice model, car accessibility only influences the location of the activity sectors “retail” and “hotels/bars/restaurants”.

9.2 Densification

Table 11 shows that increasing housing supply in “highly accessible” locations leads to a relocation of households in BCR (+ 8.5%) and in the target zones of densification (+9.8%). In the BAU scenario, we see that there is already a trend of an increasing number of households in the BCR from 2001 to 2020. The densification scenario reinforces this trend.

Table 11 shows that increasing office floor space in “highly accessible” locations does not have a significant effect on the relocation of jobs in BCR and in the target zones of densification. Indeed, the difference between the BAU scenario and the densification scenario is of the same order of magnitude as the inter-run variation. This means that the implemented policy is not enough incentive to induce a change in the choice location of jobs. As a reminder, the imposed variation of the office floor space was less important than the imposed variation of housing supply because the densification scenarios were defined with a concern for realism.

Table 11 shows that the car share tends to increase slightly in the study area between the BAU and the densification scenario. Generally, we would expect the densification to induce a modal shift from car to public transport as households relocate in denser areas better served by public transport (even if, in this scenario, households relocate in the Brussels-Capital Region while jobs do not). It seems that other mechanisms compensate this effect, in the scenario.

10 Conclusions

This case study shows that, as long as data are available, an UrbanSim-MATSim land-use/transport model can be calibrated for a large metropolitan area (3 millions inhabitants in the case of Brussels), within a reasonable time-schedule. It also illustrates how land-use/transport models can help in policy planning, by providing an estimation of the relocation effects, which in turn influence the transport indicators (i.e. mode shares, travel times, and accessibilities). Not only the final result is of interest to planners, but also the underlying mechanisms (changes in accessibilities, changes in the housing prices, reactions of the real-estate developers, all elements that are represented in UrbanSim).

However, despite the significant achievements, the integrated UrbanSim-MATSim model for Brussels still has some weaknesses. Among others, elasticities (magnitude of the policy effects) have not been fully validated and in some cases are difficult to be interpreted.

The areas requiring improvements and further research are pointed below:

First, all the models (household location choice, job location choice, hedonic price model, etc.) have been estimated with observed data, in which correlations may exist (and probably exist). It is therefore difficult to estimate with accuracy the effect of a given x explanatory variable on the y independent variable. One solution would be to estimate the parameter values using "stated preference surveys", i.e. surveys were scenarios are presented to the respondents, with uncorrelated variables, so that the effect of each variable on their choices may be derived with much higher accuracy (Louvière et al. 2000). The collection of such data could provide an important improvement to the calibration of the UrbanSim submodels, particularly the location choice models, were variables such as price, surface, number of rooms, etc., may intervene, all being correlated in the reality[7]. More generally further research should be dedicated to correlation, autocorrelation and endogeneity issues in the calibration of these models (see Chapter 1.3?).

Another field requiring further research is the validation of the models, e.g. by plausibility analysis, inter-city comparisons, inter-models comparisons, etc.

The calibration of the MATSim transport model for Brussels also requires improvement. Currently, the MATSim model is at a prototype state and was done with a small amount of time and budget. First, the model would benefit from a higher resolution network. It was noticed that the travel times deviate. This might be a problem of the network and should be researched in the future. More accurate public transport stops and travel times could be a possible improvement for the the mode choice model. A further problem seems to be the population-sampling. Experiments show a difference in spatial distribution of the resulting population. Probably, this may result from the drawing-procedure; indeed, the drawing procedure is not stratified (e.g. by zone). As another point, the MATSim model only takes into account the home-to-work trips. The inclusion of other trip purposes (home-to-school, shopping, leisure) would be an important improvement. MATSim is, in general, designed to run with full daily activity chains. However, one would need to design and test a model that combines the home and work location information

[7] To be complete, before being used in simulations, the parameters estimated by means of stated preference surveys have to be "scaled" to the actual behaviours (the scale factor being in fact a dispersion factor). Observed data are thus also necessary, together with the stated preference surveys.

from UrbanSim with information about other activities from other sources. Finally, the current model system does not include transport demand elasticity to the generalised transport cost: whathever the travel time or travel cost, the demand does not change. Including this aspect in the model would allow to simulate demand induction/cancellation effects and, again, would make it more realistic.

Other more technical improvements also should be required, for UrbanSim and MATSim, such as a reduction of the computing time, to allow a better exploration of the stochastic variations (in microsimulation, each run provides a different result and a whole set of runs is necessary to provide an average result).

Note that another integrated land-use/transport model has formerly been developed for Brussels but with a modelling framework based on the equilibrium theory (Stratec 2005). It has to be pointed out that the simulation results of the Brussels UrbanSim model cannot be easily compared with these previous results, because of the two different theoretical backgrounds (microsimulation versus equilibrium), the different underlying hypotheses, and because the UrbanSim model was calibrated in less detail, in a more limited time period.

As a general conclusion, the Brussels case study goes far beyond a theoretical simulation exercise and consists in actual policy simulations. Most of the improvements to be brought to the model and to the simulation process are known by the research team but could not be integrated, because of a lack of time or resource. In spite of its limitations the Brussels case study provides policy simulation results which were analysed and discussed. Most of them would nevertheless require further validation. This raises once again the crucial question of the need of validation data and validation processes.

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