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Methods for future land-use projections for Flanders

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Summary

This report is the second valorisation report (VR2) of the scientific project CcASPAR (www.ccaspar.ugent.be) Climate Changes and Changes in Spatial Structures. CcASPAR is an inter-disciplinary academic and Strategic Basic Research Project (SBO) financed by the Agency for Innovation by Science and Technology (IWT).

In this report, the development of a spatial allocation model is described and applied to provide future land-use projections for the region of Flanders, the northern part of Belgium. This report begins with an explanation of the linkages between climate change and land-use modelling, resulting in a detailed overview of the different types of land-use models.

Consequently, use is made of the Land Use Scanner to model the future land use for Flanders, at a resolution of 50x50 meters. The Land Use Scanner is developed to integrate and allocate future land-use demand from different sector-specific models or experts. External regional projections of land-use requirements, which are usually referred to as demand or claims, are used as input for the model. These are land-use type specific and can be derived from, for example, sector-specific models using scenarios of socio-economic developments and preferences. The total projected land-use requirement for each land-use function is allocated to individual grid-cells based on the suitability of the cell. The suitability can be interpreted as a bid price that is input for a demand-supply interaction algorithm. This definition of local suitability may incorporate a large number of spatial datasets such as the current land use, physical properties, operative policies and market forces, generally expressed in distance relations to nearby land-use functions.

To be able to define a range of probable future projection, we set up four socio-economic scenarios for the future of Flanders. The four scenarios follow the quadrants of the two axes developed by SRES (IPCC, 2000) and used by WLO in the Netherlands (WLO, 2006). These two axes define the scale at which society makes decisions and policy (national versus international) and the involvement of central government to steer developments (public versus private). The narratives are in broad lines similar to those as in other studies, but are also adapted to Flanders. These narratives are used to formulate the land-use claims and to set the influence of specific model parameters (weighing of suitability maps) to make the model run according to scenario specifications. These land-use claims are largely based on the MIRA study (MIRA, 2009) complemented with additional information, including the WLO study from the Netherlands (WLO, 2006). The WLO scenarios describe four possible futures, called Global Economy and Transatlantic market (“A” scenarios), and Strong Europe and Regional Communities (“B” scenarios).

The resulting future land-use projections, simulated using the Land Use Scanner, have a few notable features. For example, we see in the A-scenarios a typical pattern of urban sprawl occurring (as expected in these scenarios) and a strong increase in the development of housing like a “ribbon”, which is typical of Flemish urban patters. This pattern is the most visible in the outskirts of Bruges, Antwerp and Kortrijk, where new residential areas are build in former pastures and cropland. In contrast, the B-scenarios show much denser residential areas, which is expected with more strict policy rules. Second, we see in the A-scenarios a large increase in recreational nature areas. This increase occurs not only in the coastal areas at the expense of core nature areas, but also at the expense of pastures and cropland around the larger cities. Finally, in the Regional Communities scenario, there is no increase in the high density residential areas compared to the baseline land-use in Flanders. Due to the relatively low population growth and high valuation of cultural and natural services, people would likely prefer not to live in dense ‘anonymous’ cities.

Concluding, we have shown in this report the setup of the Land Use Scanner configuration for Flanders and the components (storylines, spatial claims and weights of suitability) for four scenarios. The model setup and results can be used in various follow-up activities, both CcASPAR related and separate. Possible applications of the model and/or its results include:

- More detailed incorporation of dynamics in case study areas like the Kempen;
- Assessing the effect of spatial regulation outside flood-prone zones in the coastal region of Flanders;
- Including land-use change scenarios in flood damage estimates;
- Assessing the effect of certain spatial planning policies, such as polycentric spatial policy;
- Including land-use projections in hydrological modelling.

1 Introduction

Climate change is expected to have wide-ranging impacts worldwide, including in Europe (IPCC, 2007). These impacts will hit many different sectors, including water management, agriculture, nature and urban planning (e.g. urban heat stress). Basically, (anthropogenic) climate change will change the natural boundary conditions within which our current society has organised itself. A critical link between human activity and its natural boundary conditions is land use (Heistermann et al., 2006). Land use is commonly defined by the “arrangements, activities and inputs people undertake in a certain land cover type” (Choudhury and Jansen, 1998). Land use should not be confused with land cover, which is just “the observed biophysical cover of the earth’s surface [...] confined to describe the vegetation and the man-made features” (Choudhury and Jansen, 1998) and thus disregards the functions of a specific piece of land.

The link between land use and the natural environment (including climate) goes both ways (Dale, 1997). Land use is in itself strongly defined by environmental conditions. For instance, climate and soil quality have a strong influence on the suitability of land to produce specific crops (Wolf et al., 2003) and some areas are avoided for human settlement because of environmental dangers like flooding (Stalenberg and Vrijling, 2006; Tol and Langen, 2000) or avalanches (Fuchs et al., 2005; Keller, 2004). The other way around, land use also strongly influences the natural environment in that it affects, for instance, biodiversity (Sala et al., 2000), river characteristics (Ward et al., 2009), freshwater resources (Falkenmark and Molden, 2008), bio-geochemical cycles (McGuire et al., 2001), and climate (Brovkin et al., 1999).

Moreover, land use is, just like climate, dynamic in that it varies over time. Thus, it is of importance that land use and climate change are both included in assessments of our future society. For instance, when assessing the impact of future climate change on biodiversity it is of critical importance to have an idea how the extent and dispersion of natural habitats changes due to changes in land use as well (Jetz et al., 2007). Furthermore, it has been shown that in some environmental problems the effects of land use and climate change can amplify each other, as is the case with flood risks for instance (e.g., Maaskant et al., 2009; Bouwer et al., 2010). On the other hand, land use also offers many possibilities to adapt to negative impacts of climate change as many adaptation measures are strongly land use related. Increased urban heat stress can, for instance, be alleviated by incorporating more parks and water bodies in the city design (Saaroni and Ziv, 2003); changes in habitat conditions can be accommodated by nature corridors (Thuiller, 2007); and increased flood risk can be moderated by strict spatial planning (Burby et al., 2000).

It is thus of critical importance to gain insights into future land-use change. Changes in land use can be driven by various factors. Commonly cited factors in the literature (e.g., Mudgal et al., 2008) include: demography (ageing of population, migration), economy (type of economy, growth), society (attitudes and values of people), politics (planning and regulation) and technology (intensity of use). In order to capture land-use dynamics and assess the effects of certain driving conditions on land use, modelling tools are usually employed. Because of the uncertainty inherent in future projections, this is usually done by using scenario studies. In such scenario studies a combination of driving forces that is consistent with a future storyline are used to drive a land-use model in order to assess the future spatial configuration of land use. The main objective of such scenario is to assess the effect of certain driving forces exante. This can be applied to external driving forces (which are not controllable), but can also be used to ‘test’ specific policies on their effectiveness.

The aim of this report is to serve as a methodological reference for the land-use modelling work that is performed within the CcASPAR project. Within this project a land-use model for Flanders should be developed in order to evaluate how land use in Flanders will change under different socio-economic scenarios.

This report is organised as follows. In Chapter 2, we review different methodologies that are used to model land use. Next, examples will be given of existing studies on land-use change in Flanders and the Netherlands. In Chapter 3, the methodological background of the land use allocation model will be described (including the algorithms, data, et cetera). Chapter 4 provides an overview of the different socio-economic scenarios which will be used for Flanders. In Chapter 5, we explain how the socio-economic scenarios are translated into the Land Use Scanner and which other maps are used as input for the model. Lastly, in Chapter 6 some preliminary results will be given and an outlook is given on further possible research activities within the CcASPAR project.

2 Modelling land use

Modelling land use is a wide field where geography, economy and social sciences meet. As a result, many different approaches to modelling land use have been developed, of which also various reviews exist (e.g., Irwin and Geoghegan, 2001; Verburg et al., 2004; Heistermann et al., 2006; Verburg et al., 2006; Koomen and Stillwell, 2007; Mudgal et al., 2008). Probably the overarching conclusion from all these reviews is that it is close to impossible to classify models in a consistent way. The reason behind this is that there are so many approaches and characteristics to consider (also with considerable overlap) that there are no apparent groups. This plethora of approaches and characteristics results from the wide range of questions for which models are used, different spatial scales (local to global) and the absence of a comprehensive overall theory on land-use change (Verburg et al., 2006). Instead of trying to classify models, various authors have therefore reviewed some contrasting approaches and characteristics of land-use change models (e.g., Verburg et al., 2006; Koomen and Stillwell, 2007). Some of the contrasting characteristics identified there are given in Table 1.

Table 1. Some contrasting characteristics of land use change models

dynamic	versus	static
transformation	versus	allocation
descriptive	versus	prescriptive
deductive	versus	inductive

A first important distinction is between *dynamic* and *static* models. Static models are designed to calculate a new land-use pattern for a given time directly, without any temporal steps in between. These contrast with dynamic models which work with intermediate time-steps and can thus show the evolution in land use and account for feedbacks and path-dependencies (Verburg et al., 2006; Koomen and Stillwell, 2007).

Another important distinction is whether a model deals with the *transformation* in land use, or *allocation* of land use. A transformation model starts from the current land use and simulates whether land use changes to a different type or not. Allocation models, on the other hand, need input information constraining an amount of area that is to be realized for specific land uses (claims or demand). This demand is then allocated by the model (Koomen and Stillwell, 2007).

A third distinction relates to how land-use change comes about in the model. Here *descriptive* models are mainly based on processes, whilst *prescriptive* models relate land-use change more to the attributes and location of a specific parcel of land. Prescriptive models are also known as optimization models and often assume that actors follow economic optimization in their decisions (Verburg et al., 2006).

A fourth characteristic is whether a model is *inductive* or *deductive*. Many models are inductive and rely on statistical correlations between observed land-use change and various explanatory variables. Where inductive approaches investigate land-use change using statistical techniques, deductive approaches are based on theories that predict land-use patterns from processes (Verburg et al., 2006).

Despite the large variety of models, Verburg et al (2006) also illustrate that there is a common general structure that is followed by many spatial land-use change models (Figure 1). In this structure, a distinction is made between calculating the magnitude of change and allocating this change. Both the magnitude and the allocation are driven by different factors (top two boxes in Figure 1). The magnitude of change (or claim) can be estimated using different approaches, which can be grouped in bottom-up and top-down approaches. In bottom-up approaches the total change is calculated from the spatial dynamics and allocation rules themselves (i.e. transformation), whilst in top-down approaches the total quantity of change is independently estimated from the driving forces and then put into the allocation algorithm. There are also hybrid approaches where there is a feedback loop influencing the top-down constrains during the simulation (Verburg et al., 2006).

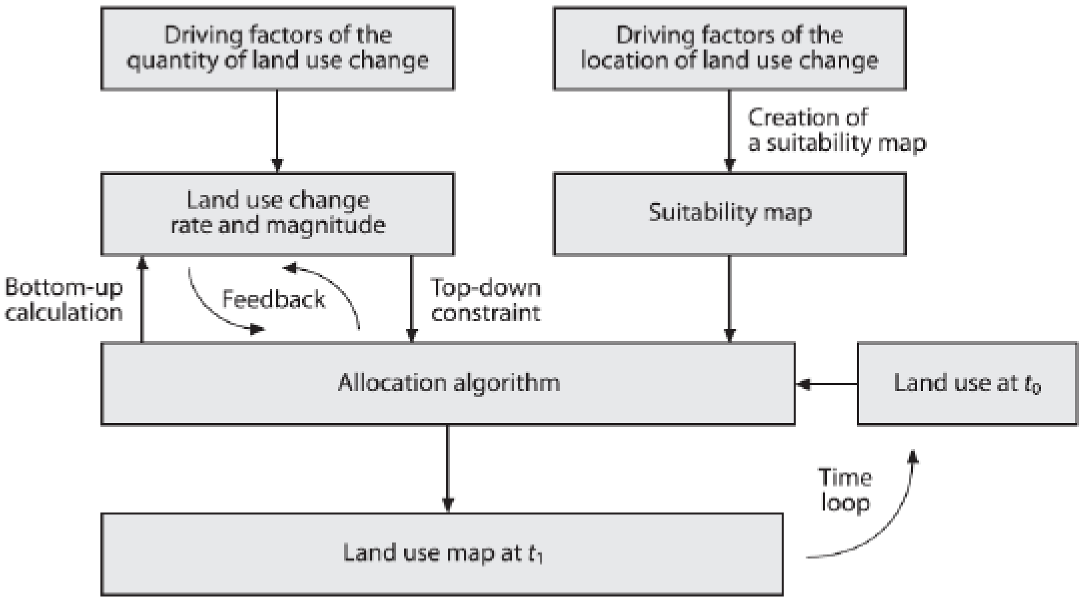

Figure 1. General structure of spatial land-use change models (Verburg et al., 2006)

For the allocation, the driving (or steering) factors are translated into suitability or preference maps, which are a key component of the allocation. Such suitability maps can be created using theory or expert knowledge of the land-use system, empirical analyses or rules based on neighbouring cells (Verburg et al., 2004). Using this suitability and the magnitude of change, an allocation algorithm will then allocate the claims in the best suited areas. This allocation algorithm can be a simple cut-off value that selects the most suitable locations, but can also be a more sophisticated algorithm that takes the competition between different land uses into account (Verburg et al., 2006). Such algorithms are often rooted in economic theory and go back to the early 19th century (Von Thünen, 1826; Ricardo, 1817). Two important theories that are frequently used in land-use modelling are bid-rent theory (Alonso, 1964) and discrete choice theory (e.g., McFadden, 1978).

In bid-rent theory the relationship between a land-use type and the value of the land is central. The underlying assumption is that the actor who can afford the most money will be the one using the land. Important factors influencing the price of land include the distance to urban centres and the available infrastructure. In simple models where this is the main feature, a land use pattern will emerge with commercial land use in the city centre and residential land use with decreasing density the further one moves away from the city centre. Industrial activities will also be in the outskirts and the edge of the city is where agrarian bidders and urban dwellers pay the same price for land (Koomen and Stillwell, 2007). Many models nowadays value land not only using distances to urban centres or infrastructure, but also many other location specific features (e.g., slope and soil quality) (Verburg et al., 2004).

The spatial land-use models described above are also sometimes referred to as top-down approaches, as first the aggregate quantity of change is established, which is then subdivided and allocated at lower spatial levels. In such an approach the role of actors who make the decisions regarding land change is often not explicitly included but assumed to follow simple interactions of economic theory. Such models can be used to explore future scenarios but are not suited to study the causes of land change. The role of actors in land change models (as link between driving forces and land change) has been reviewed in Hersperger et al. (2010). At the most extreme end there are models where decision making by actors are at the core of land change. These so-called agent-based models aim to simulate the decision-maker process. In this process the external driving forces are only part of the complex decision-making process by an actor (or group of actors). Other elements, such as institutional attitudes, learning, adaptive behaviour and collective action also play an important role (Hersperger et al., 2010). Correspondingly, these models can be used to study interactions between actors and how actor decision making results in land change. Contrasting with the top-down approaches, such models are also referred to as bottom-up. Recently, some modelling frameworks have combined top-down and bottom-up approaches (e.g., Verburg and Overmars, 2009).

There are clearly many different approaches when it comes to modelling land-use change. There is, however, not a single approach that is the best. The approach used is largely dependent on the type of answer that needs to be addressed and to a lesser degree also on the availability of data (Verburg et al., 2006). Aside from all these different modelling approaches, scale is also an important characteristic of land change models, and partly defines the appropriate approach (Heistermann et al., 2006). Land-use change models have been developed for global down to sub-national scale. At the global scale, land-use models are usually incorporated in a larger modelling framework to answer a broader question, and not so much designed to specifically investigate global land change. For instance, Integrated Assessment Models (IAMs) include land-use change components and have played prominent roles in global environmental assessments like those of the IPCC (IPCC, 2007) and the Global Environmental Outlook (UNEP, 2007). Other examples are global economy models, used in an environmental context, such as IMPACT (Rosegrant et al., 2008) and GTAP (Hertel et al., 2008) which also include a land-use component (Verburg et al., 2006). Overall, land-use modelling at the global scale is relatively scarce and faces many methodological challenges related to data availability and the integration of behaviour. For an overview on land-use models at the continental to global scale, see Heistermann et al. (2006). At the national or sub-national level there is more variety in modelling approaches. Many examples of models and cases can be found in Koomen et al. (2007). In the next two sections, some examples will be given of land-use models that have been employed in the Netherlands and Belgium.

2.1 Land-use modelling in the Netherlands

In the Netherlands, a lot of research is being performed on land-use modelling and various models have been developed and applied. The most well-established models are the CLUE model from Wageningen University (Verburg et al., 2002) and the LUMOS toolbox (consisting of the Environment Explorer and the Land Use Scanner), which is jointly developed by the various planning bureaus of the Netherlands (Borsboom-van Beurden et al., 2007). There are more models developed in and for the Netherlands, such as the PUMA model, an agent-based model for urban environments (Ettema et al., 2007).

The CLUE (Conversion of Land Use and its Effects) and LUS (Land Use Scanner) models are quite similar in setup. Both do not calculate changes in land use themselves, but rely on external input for demand of land use (Verburg and Overmars, 2007; Koomen et al., 2008). This can come from simple trend extrapolation or from a modelling framework including many different linked sectoral models. The land use that needs to be realized (known as claims) is allocated to a cell based on the suitability of that cell for that specific land use. This suitability can be a result of physical suitability, spatial policies, distance relations and competitiveness with other land-use types. The most important difference between CLUE and LUS is that CLUE works with probabilities of land-use change, where LUS is based on economic optimization. Furthermore, the CLUE model has been employed in many international and supra-national cases (Verburg et al., 2006; Wassenaar et al., 2007) where the LUS has primarily been developed for the Netherlands (Borsboom-van Beurden et al., 2007; Koomen et al., 2010). Nevertheless, the LUS is now also more and more applied in studies outside the Netherlands (e.g., the Rhine-scanner and the Elbe-scanner.

The Environment Explorer is a dynamic model using economic, demographic and environmental growth scenarios as input. Subsequently, it models the location of new activities in regions due to the specified scenarios. A cellular automata model is then used to allocate the claims for new land use. Such cellular automata models use transition functions and the value of neighbouring cells to determine whether they change state (i.e. land-use type) or not. The Environment Explorer has been used mainly in Dutch studies, for instance to explore 2030 land use under different scenarios (De Nijs et al., 2004).

The models have been employed in many different studies. A particular interesting study is the *Nederland Later* project (MNP, 2007), in which the four socio-economic scenarios ('WLO-scenarios') were evaluated and analysed in terms of land use change using the LUS.

2.2 Land-use modelling in Flanders

Various approaches for land-use modelling have been applied also in Flanders. Dendoncker et al. (2007), for instance, used a statistical downscaling technique (multinomial autologistic regression) to downscale very coarse (European scale ATEAM scenarios – Rounsevell et al., 2006) land-use change scenarios for an area in Southern Belgium.

A major effort to simulate future land use in Flanders has been performed within the scope of the *Natuurverkenning 2030* and *Milieuverkenning 2030* (resp. NARA, 2009 and MIRA, 2009). For this joint nature and environmental exploration for the year 2030 a spatial land-use model, the *ruimtelijk-dynamisch landgebruikmodel*, was developed and employed (Gobin et al., 2009). This spatial land-use model disaggregates national socio-economic and demographic forecasts to regional ones and translates these regional forecasts to land-use claims using demographic and economic sub-modules. This is done by using various mathematical relations such as the energy and transportation costs, technological developments, social values and behaviour and spatial needs per capita or employee/company. These calculations, however, were done for urban land-use classes only, while claims for agriculture, nature and forest were taken from policy goals.

3 The Land Use Scanner model

3.1 The Land Use Scanner model

The Land Use Scanner is a spatial model that simulates future land use. The model offers an integrated view of all types of land use, dealing with urban, natural and agricultural functions. Since the development of its first version in 1997, it has been applied in a large number of policy-related research projects. Applications include, amongst others: the simulation of future land use following different scenarios (Borsboom-van Beurden et al., 2007; Dekkers and Koomen, 2007; Koomen et al., 2008; Schotten and Heunks, 2001), the evaluation of alternatives for a new national airport (Scholten et al., 1999), the preparation of the Fifth National Physical Planning Report (Schotten et al., 2001b), and an outlook for the prospects of agricultural land use in the Netherlands (Koomen et al., 2005). Apart from these Dutch applications, the model has also been applied in several European countries (Hartje et al., 2005; Hartje et al., 2008; Schotten et al., 2001a; Wagtendonk et al., 2001). A full account of the original model is provided elsewhere (Hilferink and Rietveld, 1999). For an extensive overview of all publications which are related to the Land Use Scanner, the reader is referred to www.lumos.info and www.feweb.vu.nl/gis.

Unlike many other land-use models the objective of the Land Use Scanner is not to forecast the dimension of land-use change, but rather to integrate and allocate future land-use demand from different sector-specific models or experts. Figure 2 presents the basic structure of the Land Use Scanner model as applied in the GLOWA ELBE-project. External regional projections of land-use change, which are usually referred to as demand or claims, are used as input for the model. These are land-use type specific and can be derived from, for example, sector-specific models of specialised institutes. The projected land-use changes are considered as an additional claim for the different land-use types as compared with the present area in use for each land-use type. The total of the additional claim and the present area for each land-use function is allocated to individual grid-cells based on the suitability of the cell. This definition of local suitability may incorporate a large number of spatial datasets referring to the following aspects that are discussed below: *current land use*, *physical properties*, *operative policies* and *market forces* generally expressed in distance relations to nearby land-use functions.

Current land use, of course, offers the starting point in the simulation of future land use. It is thus an important ingredient in the specification of both the regional claim and the local suitability. Current land-use patterns are, however, not necessarily preserved in model simulations. This offers the advantage of having a large degree of freedom in generating future simulations according to scenario specifications, but calls for attention when current land-use patterns are likely to be preserved.

The *physical properties* of the land (e.g., soil type and groundwater level) are especially important for the suitability specification of agricultural land-use types as they directly influence possible yields. They are generally considered less important for urban functions, as our current level of technology makes it possible to build everywhere, regardless the type of soil. However, building below water level is more costly since you have to take protective measures, so the physical properties will influences the suitability for urban functions as well.

Operative policies, on the other hand, help steer Dutch land-use developments in many ways and are important components in the definition of suitability. The national nature development zones and the municipal urbanisation plans are examples of spatial policies that stimulate the allocation of certain types of land use. Various zoning laws related to, for example, water management and the preservation of landscape values offer restrictions on urban development.

The *market forces* that steer, for example, residential and commercial development are generally expressed in distance relations. Especially the proximity to railway stations, motorway exits and airports are considered important factors that reflect the locational preferences of the actors that are active in urban development. Other factors that reflect such preferences are, for example, the number of urban amenities or the attractiveness of the surrounding landscape.

The selection of the appropriate factors for each of these components and their relative weighing is a crucial step in the definition of the suitability maps and determines, to a large extent, the simulation outcomes. The relative weights of the factors that describe the market forces and operative policies are normally assigned in such a way that they reflect the scenario storylines (Koomen et al., 2008).

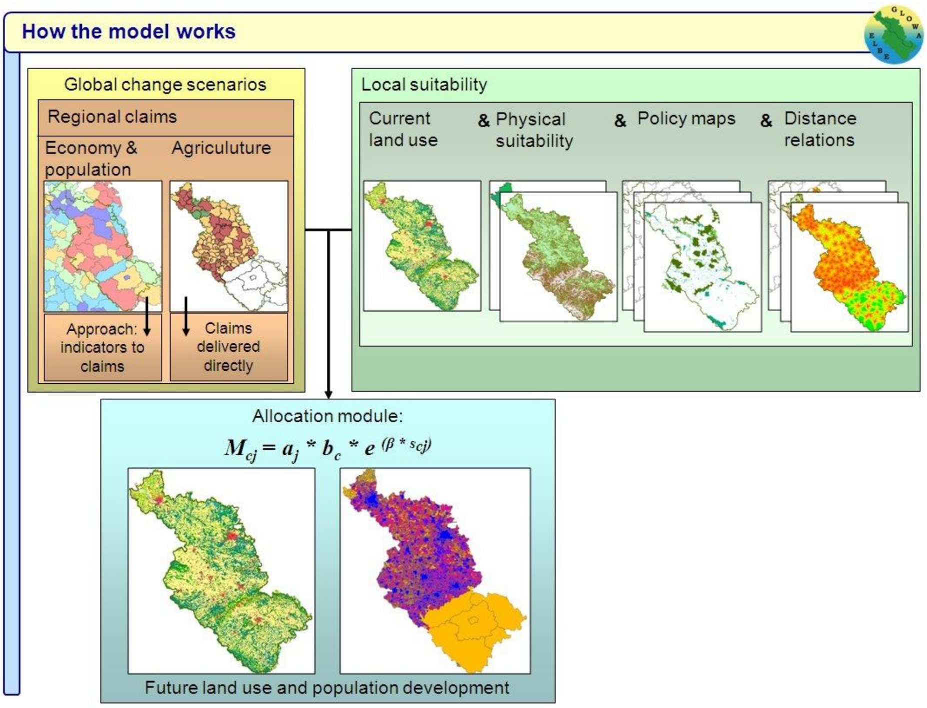

Figure 2. Basic layout of the Land Use Scanner model

3.2 Model algorithm

Currently there are two types of allocation algorithms available in the Land Use Scanner model: The continuous allocation algorithm and the discrete allocation algorithm. Using the continuous algorithm, the land use in a certain grid cell is specified by percentages of the various land-use classes that are available in the model (i.e. 12% infrastructure, 60% agriculture, 28% nature). With the discrete allocation algorithm, on the other hand, each grid cell is occupied by one land use type only. For the CcASPAR-Scanner, the continuous algorithm is used. The main reasons for this choice is the fact that this algorithm offers the possible to maintain higher resolution information than resolution of the modelling grid, which is desirable due to the considerable amount of heterogeneous land use on a sub-grid level in Flanders.

3.2.1 Continuous model

The continuous model explains the probability of a certain type of land use to be allocated at a certain location, based on the utility (in Land Use Scanner terms interpreted as suitability) of that location for that specific type of use in relation to the total utility or suitability of all possible uses for that location. This suitability is a combination of positive and negative factors that can be interpreted as benefits and costs.

The higher the suitability for a land use type in a certain cell, the higher the probability that this grid cell will be used for that type. Suitability is assessed by potential users and can also be interpreted as a bid price. After all, the user deriving the highest benefit from a location will offer the highest price. Furthermore, the model is constrained by two conditions, namely, the overall demand for each land use function, and the amount of land which is available. By imposing these conditions, a doubly constrained logit model is established, in which the expected amount of land in cell c that will be used for land use type j is essentially formulated as:

$$M_{cj} = a_j b_c \exp(S_{cj}) \quad (1)$$

in which:

- M_{cj} is the amount of land in cell c expected to be used for land use type j;
- a_j is the demand balancing factor (condition 1) that ensures that the total amount of allocated land for land use type j equals the sector-specific claim;
- b_c is the supply balancing factor (condition 2) that makes sure the total amount of allocated land in cell c does not exceed the amount of land that is available for that particular cell;
- S_{cj} is the suitability of cell c for land use type j, based on its physical properties, operative policies and neighbourhood relations

The continuous model is best applicable with grid cells larger than 50x50m where more than one type of land use per grid cell can be allocated (i.e. heterogeneous cells).

A more extensive mathematical description of the model and its extensions is provided in Hilferink and Rietveld (1999). For an extensive discussion of the discrete allocation model and its relation to claims sets we refer to Koomen et al. (2008).

3.3 Suitability maps

As described in Section 3.1, the land-use claims are realized by the allocation algorithm making use of local suitability of the grid cells for the different land uses. This suitability is a crucial component in the allocation of future land use. The suitability of a grid cell can be interpreted as the net benefits (benefits minus costs) that a land-use function derives from that specific location and are expressed in Euro per square metre. The higher the suitability for a specific land-use type, the higher the probability that the cell will be used for the respective type. For every location the suitability or attractiveness for different land-use types is described, based on a number of site specific characteristics. The factors, influencing this suitability can be divided into three groups:

- Present land use;
- Policy maps;
- Thematic maps (e.g., distance relations).

The value of a grid cell in a suitability map can also be negative indicating that the cell is highly unsuitable for a certain land use. This could, for instance, be the case for a grid cell in a national park for the land-use type ‘Commercial’.

Not all land-use classes are modelled in the Land Use Scanner using claims and suitability. Some land-use types are exogenous, meaning they are not modelled but specified directly. This also means that the allocation module is not allowed or able to allocate endogenous (i.e. modelled) land use in locations (i.e. grid cells) where these exogenous land use types are already present. Infrastructure, water bodies and exterior are typical exogenous data types. Exogenous developments such as new roads or waterways or the creation of new land in water areas can be specified in a scenario.

4 Socio-economic scenarios for Flanders

The Land Use Scanner model requires external input on the land-use claims that are to be allocated within the model. Within the CcASPAR project, the aim is to explore a wide range of scenarios for the future that describe autonomous economic and demographic future developments and their corresponding land-use claims. These scenarios are autonomous in the sense that they do not include policies specifically aimed at further regulating land use beyond what is currently in practice or policies that aim at climate adaptation. These scenarios, however, can at a later stage be complemented with parameters that allow the evaluation of the effect of such specific policies. Future developments are inherently unknown, which means that many different futures are possible. In order to assess a proper range of possible futures, a scenario-axis method is often used. In this method some key uncertainties are identified and used to form axes to create quadrants that represent the different combinations of those key uncertainties. The most well-known example of this practice stems from the Special Report on Emission Scenarios (SRES), which illustrate four families of scenarios that are also used in the IPCC assessments (IPCC, 2000). The two axes used in the SRES scenarios are the scale of development of markets and cooperation (globalisation versus regionalisation) and the role of the government in providing services (public versus private).

Figure 3. The scenario axis and four scenario families (A1, A2, B1, and B2) as developed by the IPCC (2000). Also shown is the terminology used in this report (GE, TM, GC, and RC). Source: WLO (2006).

Many other studies use similar or the same axis as the SRES ones to define four contrasting scenarios. Examples include the PRELUDE scenarios (EEA, 2007), the EURuralis scenarios (Eickhout and Prins, 2008), the WLO scenarios (WLO, 2006) and the scenarios used in the Foresights study (Evans et al., 2004). Therefore, these contrasting four views of future development will also be explored for Flanders. Each scenario consists of a set of assumptions that is internally consistent with a specific storyline. In order to derive quantitative estimates for land use claims under the different scenarios, the first step is to quantify how demographic and economic conditions (or even more conditions, such as the environment, technology and political) will develop under the different storylines. Once that is established, their (regional) effect on different sectors in terms of land area needs to be established. To support this various sectoral models can be used. The WLO study, for instance, used over forty different models to quantify future developments for their four scenarios. The output of these models was subsequently used in a land change model to evaluate future land-use patterns and developments. Such a comprehensive assessment, however, is not available for Flanders and costs a lot of resources. For this study use will therefore be made of existing scenarios in Flanders and the Netherlands.

4.1 Existing scenario studies for Flanders

4.1.1 Demographic projections

The *Federaal Planbureau* of Belgium has made a projection on demographic developments up to the year 2060 (Federaal Planbureau, 2008). Only a single projection is given, with no further differentiation between scenarios. Looking up to 2030, which is the horizon of many scenario studies, an increase in population of 12% (with respect to 2005) is projected for Flanders. This corresponds with an increase in the overall population of 0.46% per year and is mainly the result of immigration and a temporarily increased birth rate. The total population will also become older and the share of young people will decrease. Many demographic parameters are given, including percentages of certain age categories, life expectancy and migration rates. The total population of Flanders is forecasted to increase from 6.12 million in 2007 to 6.78 million in 2030 (Federaal Planbureau, 2008).

Besides a general increase in total population, it is also expected that household size will become smaller, which results in an increase in the number of households. This downsizing of households has been studied in-depth by Willems (2007), who projected family sizes from 2004 to 2025 and differentiated between two scenarios: moderate and strong downsizing (Table 2). Willems shows for Flanders that the amount of households will increase from 2.48 million in 2004, to 2.79 million under the moderate down-sizing scenario and to 2.84 million households under the strong down-sizing scenario (Willems, 2007). Note that Willems used population estimates of 6 million for 2004, and 6.2 million for 2025, which is substantially lower compared to the population estimates of Federaal Planbureau (2008; see above).

Table 2. Estimates of number of households for Flanders from Willems (2007).

Year	# households (millions)	# persons per household
2004	2.48	2.40
2025 mod. down-sizing	2.79	2.22
2025 strong down-sizing	2.84	2.18

4.1.2 MIRA and NARA scenario studies

The amount of comprehensive scenario studies for Flanders is limited. There are various sectoral scenario studies though, which are relevant to the current study. The most notable are the studies of Gavilan et al. (2006) and Van Bockstal et al. (2006). In Gavilan et al. (2006), four agricultural scenarios were quantitatively assessed for 2020 using a socio-economic and hydrological model. Van Bockstal et al. (2006) developed four scenarios on rural development in 2030. The most comprehensive scenario study for Flanders is probably the joint MIRA and NARA study. These reports respectively explore the future of Flanders in 2030 from an environmental (MIRA) and nature (NARA) perspective. In the MIRA report two scenarios are explored: a reference scenario with continuation of current policy and a 'Europe' scenario in which all European environmental goals (on energy and climate, water quality and air quality) are met. The NARA study starts with these two scenarios and projects three policy scenarios related to nature conservation on each of them (separating functions, reference, and combining functions).

The MIRA scenarios (reference and Europe) are based on the same demographic forecast as described in Section 4.1.1. In addition, economic forecasts are used. Economic forecasts for Flanders are usually performed with a time horizon of five years into the future by the *Federaal Planbureau* (FPB). However, for the MIRA/NARA explorations forecasts with a longer horizon (2030) were also provided by the FPB (Federaal Planbureau, 2008). Here they assume a yearly increase in GDP of 2%, which is slightly lower than the average observed over the 25 years before 2005. Also information on the contribution of different sectors to gross added value and employment are given (see MIRA, 2009).

The MIRA scenarios have been made spatially explicit by Gobin et al. (2009), using a land-use change model with ten discrete classes. To do so, they used a wide variety of sources concerning forecasts and sectoral projections.

4.2 WLO scenarios for the Netherlands

The WLO study (WLO, 2006) contains four scenarios, created using the scenario axes method (Figure 4), as described in the previous section. The two key dimensions used to create these four scenarios are i) the extent of international cooperation (national versus international), and ii) the way the collective sector is shaped with respect to the private sector (public versus private).

Figure 4. The scenario axis technique used to frame four scenarios for the Dutch WLO scenarios (after CPB et al. 2006).

The WLO scenarios aim to describe ultimate changes in the physical environment under different autonomous economic, demographic, and social developments. These scenarios are described according to the two key uncertainties of scale, namely; the development of trade markets and the mode of provision of public services. National policy is a very important factor when it comes to shaping the physical environment, especially in a dense populated country such as the Netherlands and Belgium. In order not to disturb the effects of external drivers, national policy (with respect to the physical environment) has been kept as equal as possible between the different scenarios, with differences between national policy in the scenarios being the result of the exogenous drivers (from outside the Netherlands) underpinning the separate scenarios. The results of the WLO scenarios will be used as an important reference to compare different national policy options in such a future world. The narratives of these four scenarios are briefly described below.

<u>Global Economy</u>

The Global Economy world is one of free international trade. The EU expands eastwards and the WTO is successful in linking trade between different countries. There is, however, no political integration and international cooperation on various global issues fails. Welfare increases strongly with economic growth and population grows strongly due to immigration. This growth in economy and population is the highest among the four scenarios.

<u>Strong Europe</u>

In the Strong Europe scenario there is a focus on international cooperation and the EU gets a relatively influential role in global economy and politics. The international cooperation successfully addresses various global (environmental) issues. Social-economic policy aims at solidarity and there are high investments in research and education. There is considerable economic growth and some population growth due to immigration.

<u>Transatlantic Market</u>

In the Transatlantic Market scenario the EU does not become a political success as member states hold on strongly to their sovereignty. Trade between the EU and US does grow considerably though, resulting in a new merged market. Individual responsibility is stressed by the national government, resulting in limited social security systems and public facilities. Innovation, competition, productivity and the economy grows strongly (more than SE, less than GE) while population increase is limited. International environmental issues are not being resolved and inequity in income grows.

<u>Regional communities</u>

In Regional Communities the international political and economic cooperation fail. The world splits into separate trade blocks and international environmental issues are not resolved. Still the pressure on the environment is the lowest here since growth in economy and population is rather low in this scenario. Social cohesion stays in place and solidarity takes an important place in the political landscape. There are limited incentives for innovation or high productivity resulting in relatively high unemployment rates. Economic growth is the lowest from all four scenarios.

4.2.1 Methodology

For the WLO study the Netherlands has been divided into three zones: the Randstad (metropolitan centre of the Netherlands), the transition zone (the provinces in the centre of the Netherlands) and the rest of the Netherlands. For each scenario and zone eight different themes are considered which together provide a comprehensive projection of a future world. These themes (or sectors) are: housing, employment, mobility, agriculture, energy, environment, nature and water.

There are several drivers considered in the WLO scenarios. These are:

- Demography (immigration being a key variable);
- International economic and political developments (functioning of EU and WTO);
- Technological developments (speed of innovation);
- Developments in economic production structure (demand for space; pollution);
- Social-cultural developments (degree and rate of individualism);
- Economic growth;
- Climate change (flood defences based on differentiated safety or equity).

To assess the impacts of these drivers on the different themes recognized in the WLO study use is made of a large variety of models, including models of the international and national economy, the demography, on mobility, energy, emissions and air quality. In total around forty different models are used and linked to derive the parameters for each scenario. As the main focus of WLO is on the physical environment, results for given themes are often calculated in the amount of houses, area covered by specific land uses or the amount of cattle.

4.2.2 Projections

Projections for a variety of indicators for the Netherlands under the four different scenarios are summarized in Table 3. The table shows clearly that the two private oriented scenarios yield the highest economic growth, where the highest population growth is expected in the international oriented world. With respect to the changes projected for 2040, it is important to mention that for many issues the largest changes are projected before 2020. This is mainly the result of a decrease in population growth (or even a decline) that is project to occur after 2020, but also due to changes in the structure of the economy (e.g., increasingly more services oriented). Because of these developments the pressure on the physical environment will decrease. This is the case, for instance, for the area needed for business areas, industrial complexes and roads; but also congestion in traffic will not increase in three of the four scenarios compared to the present. The Global Economy is the only scenario where pressure on the physical environment continues to grow rapidly.

In terms of land use, most scenarios show a decrease in agricultural area (except for intensive horticulture) and an increase in natural area and industrial area. This increase in natural area also occurs mostly before 2020, as it is for a large part the result of the establishment of main ecological network (Ecologische Hoofdstructuur; EHS) areas in the Netherlands, which should be completed by 2018, according to current policy.

Table 3. Summary of the main results for the four WLO scenarios. Taken from the website of the WLO study (www.welvaartenleefomgeving.nl).

	Global Economy	Strong Europe	Transatlantic Market	Regional Communities	unit
Demography and economy	*level in 2040*				
Inhabitants	19.7	18.9	17.1	15.8	million
Number of households	10.1	8.6	8.5	7.0	million
GDP per capita	221	156	195	133	index 2001=100
Ageing (population above 65)	23	23	25	25	%
	Global Economy	**Strong Europe**	**Transatlantic Market**	**Regional Communities**	**unit**
Home	*mutations compared to 2002*				
Single-family dwelling	+ 1.9	+1.1	+1.0	+0.3	million
Multiple-family dwelling	+1.2	+0.6	+0.5	+0.1	million
Industrial areas	*changes compared to 2002*				
Industrial plants	+ 43	+ 18	+ 23	-3	%
Offices	+ 34	+ 19	+ 16	+ 1	%
Informal work locations	+ 46	+ 27	+ 25	+ 7	%
Mobility	*changes compared to 2002*				
Passenger transport	+ 40	+ 30	+ 20	+ 5	%
Transportation of goods in ton km	+ 120	+ 40	+ 65	-5	%
Congestion hours	70	0	-10	-70	%
Agriculture	*changes compared to 2002*				
Agricultural area	-15	-15	-15	-10	%
Glasshouses	+ 60	-15	+ 5	-45	%
Number of dairy cows	+ 25	-5	-5	-15	%
Number of pigs	-5	-55	-5	-55	%
Energy	*changes compared to 2002*				
Use of energy	+ 55	+ 10	+ 40	-5	%
Use of coal	+ 195	+ 40	+ 155	+ 35	%
Stock of natural gas	-95	-85	-85	-75	%
Share renewable energy (electricity)	+ 1	+ 34	+ 2	+ 24	%
Environment	*changes compared to 2002*				
CO2 emission	+ 65	-20	+ 30	-10	%
Chronic illness due to particulate matter (PM10)	+ 22	+ 5	+ 26	+ 1	%
Waste (total)	+ 100	+ 44	+ 53	+ 11	%
Nature and recreation	*changes compared to 2002*				
Nature areas (reserves)	+ 20	+ 25	+ 18	+ 22	%
Sport and recreation areas	+ 75	+ 48	+ 33	+ 18	%
Areas with low nitrogen deposition	0	+ 53	+ 3	+ 51	% point

4.3 Four scenarios for Flanders

For CcASPAR, four contrasting scenarios will be developed. The current study adds to the other land-use projections that have been prepared for Flanders, such as those by Gobin et al. (2009). First, the current study differentiates between four scenarios, allowing the assessment of implications of a wider range of socio-economic developments on land-use patterns, and second, these new projections are autonomous developments, that can be regarded as four equally valid ‘reference’ scenarios. Third, and importantly for the CcASPAR project, the land-use scenarios developed here have been extrapolated to the year 2050. This allows the comparison with climate change projections that typically foresee greater changes further into the future.

Each of the newly developed scenarios consists of a narrative and a set of land-use claims. The four scenarios follow the quadrants of the two axes developed by SRES

(IPCC, 2000) and used by WLO in the Netherlands (WLO, 2006). These two axes (see Figure 3) define the scale at which society makes decisions and policy (national versus international) and the involvement of central government to steer developments (public versus private). The narratives are in broad lines similar to those as in other studies, but are also made Flanders specific. For naming these scenarios we follow the names given by WLO: Global Economy (A1), Transatlantic Market (A2), Strong Europe (B1) and Regional Communities (B2). For the general narratives of the scenarios, the reader is referred to Section 4.2. Below the Flanders specific narratives will be described. These narratives are used to formulate the land-use claims (see Section 5.2), and to set the influence of specific model parameters (weighing of suitability maps) to make the model run scenario specific.

<u>Global Economy (A1)</u>

The Global Economy scenario is characterized by a relatively weak governmental influence and strong globalisation. The Global Economy scenario has the largest growth in population and economy, resulting in the largest pressure on the finite amount of land in Flanders. Because of associated individualisation, the size of households decreases, resulting in an even larger demand for residential land use. Because of scaling up processes and increased global trade, agricultural land use is the least competitive and is the main component making space for other components. Environmental awareness is relatively low and nature is not seen as an important land use. Mainly the recreational use of nature areas is deemed important in this scenario with a relatively high standard of welfare. Governmental steering of spatial developments and protection of areas with cultural or natural values is low. There is also little policy to direct new urban developments, increasing the risk of (further) urban sprawl.

<u>Transatlantic Market (A2)</u>

In the Transatlantic Market scenario, there is a relatively little governmental interference, but unlike the A1 scenario, there is a more regional focus. Population growth is relatively low in this scenario compared to A1 due to less immigration, but because of strong reduction in the size of households, there is still a decent demand for new residential land use. The regional character of this scenario puts agriculture at a higher priority compared to the more global oriented scenarios (A1/B1) because of the wish to remain (largely) self-sufficient in food production. Combined with low environmental consciousness, this means that natural areas are under strong pressure to convert to other types. Mainly the combination with agriculture is a competitive option for nature development. Similar to the A1 scenario, there is little policy to steer urban development or protect natural areas (VEN areas). Areas of cultural heritage (ankerplaatsen) are protected up to a certain degree because of the regional focus of this scenario.

<u>Strong Europe (B1)</u>

In contrast to the A2 scenario, the Strong Europe scenario is characterized by strong governmental influence and globalisation. This globalisation results, via immigration, in a strong demand of urban land use, though the reduction household size is not as big as in the A-scenarios. Urban development is, however, much more steered to combat urban sprawl and develop compact cities. Also designated natural areas are much better protected, though this is less the case for cultural heritage. Like in the A1 scenario, agricultural land use is the least competitive and most likely to decrease.

Regional Communities (B2)

The Regional Communities scenario denotes strong governmental influence and a regional focus. Like in the B1 scenario, environmental consciousness is large in this scenario. This result in the protection of natural areas (VEN), but also areas of cultural heritage are considered important. The amount of urban development is the least in this scenario, because of low population growth, low immigration and a limited reduction in household size. The focus of new nature development is on the combination with agriculture in order to limit foreign dependency for food security.

5 Modelling setup for Flanders

In order to model the spatial implications of the four socio-economic scenarios described in Chapter 4, a Land Use Scanner configuration has been developed for Flanders. This setup uses the continuous model algorithm (see Section 3.2.1), meaning that each cell does not have a single land use, but rather a percentage of each type (which adds up to 100%). The spatial resolution on which the model works is 50x50 meters, but the underlying data used to calculate the percentages of each land-use type is on a 5x5 meters resolution. In this section the configuration for Flanders will be further presented. The input information used for the modelling, of which the main elements are the base map, the land-use claims and the suitability maps with their weighting for the different scenarios, will be discussed in the following sections.

5.1 Base map

An important part of the setup of the Land Use Scanner is the base map of the region, containing the baseline situation with the current spatial distribution of the different land-use classes that are to be modelled. Many land-use or cover datasets are designed with a specific focus, i.e. on the urban environment (settlements, services and industrial activities) while generalizing the rural environment (agriculture and nature), or the other way around. As the CcASPAR-scanner is intended as an integrated modelling framework of different sectors including those in rural and urban areas, it was decided to combine different spatial datasets in order to derive a base map for the model that includes information with sufficiently detailed classes and that is also spatially accurate.

Table 4. Classes distinguished and modelled in the CcASPAR-scanner.

	Land-use class	Source
1	Residential – high density	Top10*
2	Residential – medium density	Top10*
3	Residential – loose buildings & ribbons	Top10*
4	Industrial	Top10
5	(non-)Commercial services	Top10
6	Horticulture	Top10
7	Cattle farming	lbgb2007
8	Agriculture	lbgb2007
9	Nature – Agriculture	combi-map
10	Nature – Forestry	combi-map
11	Nature – Recreation	combi-map
12	Core nature	combi-map
13	Infrastructure (fixed)	Top10
14	Water (fixed)	Top10

Last (3%) cells assigned with CORINE 2006

*Differentiated using various neighbourhood analyses

The base map that is designed for the CcASPAR-scanner consists of 14 classes (Table 4). Two of these classes (infrastructure and water) are exogenous, meaning that they are fixed in the model and not dynamically modelled. There are five urban categories:

three residential classes, and an industrial class, and a (non-)commercial services class. Three agricultural classes are distinguished: horticulture, cattle breeding and crop cultivation. The last four classes are dedicated to nature. There is one class consisting of nature only, and three multifunctional nature classes where nature is combined with recreational, agricultural or forestry land use to represent the different multi-functional uses that are actually present in natural areas in Flanders.

The base map is a compilation of various other sources. The main source of each class is indicated in the table above. The Top10 vector map has mainly been used for the land-use classes with buildings and the horticulture (greenhouses). From the Top10 vector data the layers of CO_Building, CO_ParicularPolyConstruction, HY_WaterSurface, HY_Watercourse_Surface, LC_LancoverZone, RA_RailwaySurface, RO_ConnectingRoadSurface and RO_OrdinaryRoadSurface were used for this. The residential classes originate from a single class of the Top10 data. This class has been differentiated using various neighbourhood analyses in order to distinguish different urban densities. The classes distinguished are high density residential (cities and centres of large towns), low density residential (suburbs and villages) and loose buildings and ribbon development. This differentiation has been made by first determining the urban density (using a 30x30 cell kernel) using all land-use classes. This resulted in a differentiation between high and low urban densities. The low urban density part has subsequently been split by looking at the density of residential land use in the vicinity (using a 99x99 cell kernel). By doing so low density residential neighbourhoods could be distinguished from ribbon development and buildings in rural areas. After this differentiation, additional neighbourhood analyses were carried out to ensure that individual blocks would fall entirely in a unique category.

An agriculture map with agriculture and cattle farming land-use classes was derived from the ‘landbouwgebruikspercelenkaart 2007’ (lbgb2007) and the different nature classes come from a combination map. This map has been derived from the Biological Valuation Map which has been interpreted in the context of the Special Protection Zones, the spatial destination plans and the agricultural land-use map. This was necessary because land-cover and land-use are substantially different in the case of nature. High nature values can exist in different contexts of land use.

All data have been rasterized to 5x5 m grids and added together. Obviously, there are important overlaps between the three maps described above. When combining them the nature combination map has been given the highest priority as it includes multifunctional classes (which are bound to overlap with the agriculture map described above), and which are deemed crucial for representing the actual Flemish landscape. The second highest priority was then given to the Top10 map because of its superior spatial resolution, compared to the agriculture map (i.e. individual buildings are distinguished in the Top10 and should take priority over the more general areas of the lbgb2007). Finally, the agriculture map then had the lowest priority.

After combining the maps as described above, there were significant areas with no data left. This is mainly because the Top10 vector data has a class of ‘non-specified unvegetated land’. These areas with no data are often parking lots and areas between individual buildings in industrial or commercial complexes. To fill up these areas the most recent CORINE land cover data has been used. This was done because the CORINE data fully covers Flanders, and it has more general industrial/commercial classes that do include the areas between the individual buildings. The CORINE 2006 seamless vector maps[1] were used for this purpose and rasterized to the same 5x5 m resolution as the rest of the maps. The total amount of cells that needed to be filled

[1] http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version

with the CORINE 2006 constitutes about 3% of all cells. As expected most of the filled cells were residential or industrial land use, but there was also a significant amount of agricultural land use.

5.2 Land-use claims for scenarios

In order to formulate land-use claims for the four scenarios, the MIRA study (Flanders) will be combined with the WLO study from the Netherlands. In this respect, the MIRA study will serve as an anchor point to quantify land-use claims. The scenarios developed by MIRA, specifically the 'Europa' scenario, fall within the B1 quadrant of the SRES/WLO scenario space (Gobin et al., 2009). Hence, the MIRA results have been leading in quantifying the land-use claims for the Strong Europe (SE) scenario in this study. In order to quantify the land-use claims for the other scenarios, use is made of the WLO scenario set development in the Netherlands (WLO, 2006). Next, the different land-use claims as defined in the WLO study were simply translated to the other scenarios, based on how the B1 scenario compares to the Global Cooperation scenario (GC), see also Figure 3 in Chapter 4. Of course, it is important to keep in mind that this is a simplification of the scenario construction procedure, and the regions of Flanders and The Netherlands are comparable only to a limited extent. But the comparison and translation of the other scenarios allows a quick expansion of the scenarios space, while making use of the extensive work that has gone into the WLO scenarios. In the following sections the derivation of land-use claims for the modelled land-use classes is addressed in more detail.

Scenarios were developed for the years 2030 and 2050. The projections for 2050 follow in general the same lines as the projections for the year 2030, but are extrapolated by another 20 years. It should be noted that given the simple extrapolation of socioeconomic information, they are only intended for illustration, and do not rely anymore on the original socioeconomic projections from MIRA and WLO, on which the 2030 scenarios presented here are based on.

5.2.1 Land-use claims residential

There are three types of residential land use distinguished in the LUS for Flanders. These are i) high density residential (centres of large towns/cities), ii) low density residential (suburbs and villages) and iii) loose buildings and ribbon development. The land-use claim for these three classes has first been determined in total, and then differentiated between the three classes. The total residential land-use claim is based on estimates of population and household size.

Population

Population growth from 2005 to 2030 in the MIRA study is 12%. This estimate has also been adopted in this study. Next, based on the differences in population growth between the WLO scenarios, the population growth of the other scenarios has been established (Table 5).

Table 5. Population forecasts for the four scenarios.

	WLO NL (%/year)	CcASPAR (2030)	Population 2030
Baseline (2005)			6055320
A1	+0.53%	+14%	6903065
A2	+0.16%	+5%	6358086
B1	+0.42%	+12%	6781958
B2	-0.05%	+0%	6055320

Household size

Using the size of the average household, the population estimates can be recalculated into the number of households in each scenario. In 2005, the average household size was about 2.4 persons (see also Section 4.1.1). It is expected that this will decrease in the future, though the amount of decrease may change. Following Willems (2007), we use two projections of household size reduction: strong and weak reduction. Following the WLO study, who also assumed two projections for household sizes, we apply strong reduction in household size to the A-scenarios, and a weaker reduction in household size to the B-scenarios. The two projections of Willems (2007) have been linearly lowered further, as the time horizon of this study is the year 2030 and the projections of Willems are for 2025 (Table 6).

Table 6. Estimates of household size, amount of households and relative increase in number of households.

	Household size (2030)	# households (2030)	number of households
A1	2.15	3210728	+28%
A2	2.15	2957249	+18%
B1	2.20	3082708	+23%
B2	2.20	2752418	+10%

Residential area

The increase in the number of households has been used to formulate the residential land-use claim. Table 7 shows that the increase in households calculated earlier compares well to the increase in residential land-use from the WLO study. Comparing the increase in the number of households in the B1 scenario to the MIRA increase in residential land use, shows the latter is slightly higher (16 compared to 18%, respectively). We therefore adjusted the percentage increase in residential land use slightly, as shown in column 5. These numbers would in the absolute land-use claims given in column 6.

Table 7. Land-use claim for residential land-use in CcASPAR and comparison to WLO and MIRA.

	number of households	WLO NL residential land use (2040)	MIRA residential land use (2030)	CcASPAR residential land use (2030)	**CcASPAR land-use claim (ha)**
A1	+28%	+31%		+28%	**65765**
A2	+18%	+15%		+17%	**39928**
B1	+23%	+16%	+18%	+20%	**46975**
B2	+10%	+4%		+8%	**18790**

Subdivision residential classes

The land-use claims for the scenarios given in Table 7 are divided over the three distinguished residential classes. The starting position for this subdivision is the current relative occurrence of each class (roughly 8%, 70%, 22%). For the Transatlantic market scenario, this split has directly been used to derive the land-use claims for the three residential classes. In the global oriented scenarios (Global Economy and Strong Europe) a relative high portion of the claim has been assigned to the high density class. For the Global Economy scenario the ribbon development class also increased to simulate the increased urban sprawl, whilst for the Strong Europe scenario the claim of ribbon development was lowered considerably in order to illustrate the governmental policies regulating urban sprawl. In the Regional Communities scenario, the claim for the highest density class was set to zero, illustrating the lack of desire to live in anonymous high density urban areas.

5.2.2 Land-use claims industry and services

Economic growth

Every year, the Federal Planbureau (FPB) of Flanders publishes five year forecasts for economic growth. Hertveldt et al. (2009) have extended this to 2030 for a study related to transportation in Belgium. They assume an annual growth of the gross domestic product (GDP) of 2% per year. This is roughly equivalent to GDP developments in the last couple of decades. The MIRA study also uses this assumption for their 2030 land use projections. An annual GDP growth of 2% per year is just a bit above the B1 scenario assumption from the Dutch WLO study (Table 8). Hertveldt et al. (2009) also mention that the long term GDP growth may be a bit lower because of the recent financial crisis, in which case an average growth of about 1,5% per year can be used. For CcASPAR, growth percentages similar to WLO are used, but then slightly increased for the B-scenarios in order to be closer in line with the projections of the FPB.

Table 8. Economic growth forecasts used in WLO and MIRA.

	WLO NL (%/year)	MIRA (%/year)	CcASPAR (%/year)
A1	+2.6%		**+2.5%**
A2	+1.9%		**+2%**
B1	+1.6%	+2.0%	**+1.8%**
B2	+0.7%		**+1.0%**

Growth in land use area

Formulating a land-use claim in hectares for commercial and industrial land use is not as straightforward as taking economic growth forecasts for Flanders. Table 9 shows growth percentages of economic growth in the Netherlands from the WLO study and the associated increase in land use in the four different scenarios. The percentages from Table 9 can be plotted and result in the relationship shown in Figure 5.

Table 9. GDP growth and growth in land-use area between 2005 and 2030 in the WLO study

	GDP growth (%/year)	Area industry/ business ((%/2030)	Area offices (2030)
A1	+2.6%	+29%	+34%
A2	+1.9%	+19%	+18%
B1	+1.6%	+13%	+19%
B2	+0.7%	+1%	+4%

When looking at the increase in area of commercial land use (business area and offices) in MIRA for 2030, the increase (2.8% by 2030) is relatively low compared to the Dutch projections. Also in comparison with the historic growth of industrial area in Flanders, the MIRA increase is relatively low. For instance, the *Ruimtelijk Structuurplan Vlaanderen* (RSV, 2004) provided a target of +13% over the 1994-2007 period, corresponding to a +24% increase over 25 years. The evaluation of the RSV in 2010 (Voets et al., 2010) shows that the actual increase between 1994 and 2007 was 8.2%, which would be a 16% increase over 25 years when extrapolated linearly. This historical trend is considerably larger than the growth assumed by MIRA. On the other hand, it is very much in line with the relationships extracted from the WLO study (Figure 5). For instance, when using an annual GDP growth of 1.8%, industrial/business areas would increase about 17% over 25 years.

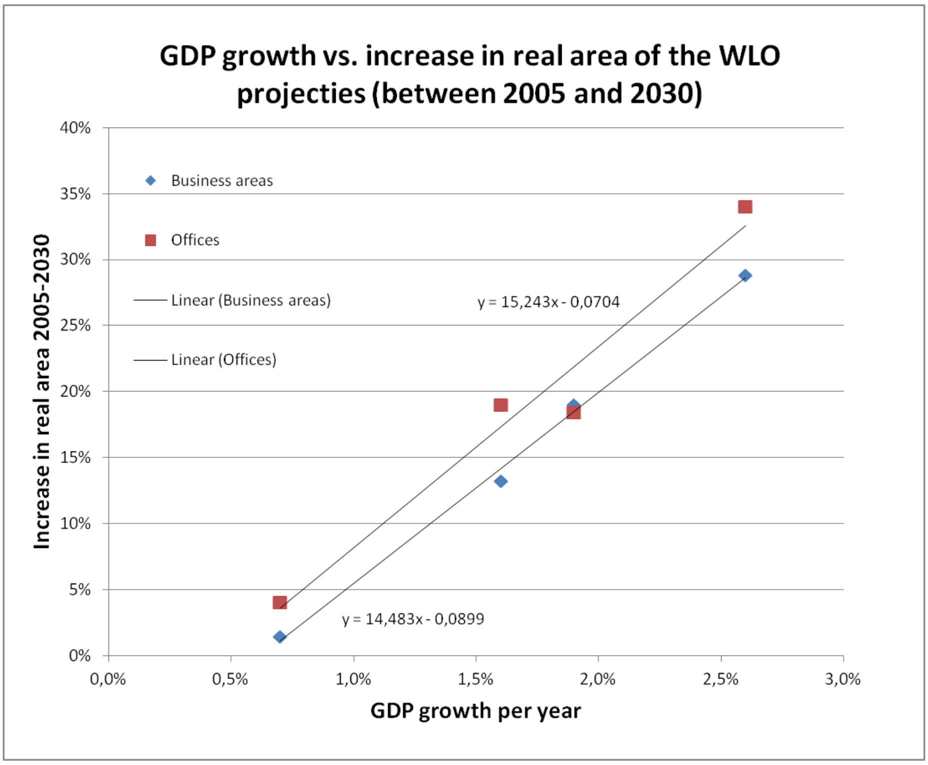

Figure 5. GDP growth per year versus the increase in area of business areas (blue diamonds) and offices (red squares).

As the MIRA estimates of growth for industrial and commercial land use seem to be rather low, the relationships found in the WLO study between GDP growth and area growth was chosen to be used for the current study. Using the linear relationships found in Figure 4, the resulting changes in area are given in Table 10.

Table 10. Increase in industrial and commercial land use.

	Economic growth (%/year)	CcASPAR industrial land use (2030)	CcASPAR commercial land use (2030)	**CcASPAR land-use claim industry (ha)**	**CcASPAR land-use claim commercial (ha)**
Now				**20682**	**2732**
A1	+2.5%	+27%	+31%	**5624**	**849**
A2	+2%	+20%	+23%	**4127**	**641**
B1	+1.8%	+17%	+20%	**3529**	**557**
B2	+1.0%	+5%	+8%	**1134**	**224**

5.2.3 Land-use claims nature

In total, four nature related land-use classes are distinguished. Besides natural areas themselves, also three combination classes are distinguished where nature is combined with other land-use types. These are i) nature-agriculture, ii) nature-forestry, and iii) nature-recreation. Formulating a land-use claim for these classes is not easy, as both MIRA and WLO do not distinguish similar classes. It is therefore less straightforward to use them as starting points. In MIRA, an 11% increase in natural area can be observed, as illustrated by Table 11.

Table 11. Nature related land use increase from MIRA.

	MIRA (2005) in ha	MIRA (2030) in %
Nature	75780	+25%
Forest	129769	+5%
Recreation	16094	0%
Total	221643	+11%

Moreover, the nature claim in the WLO study is based on the assumption that designated natural areas will be realised in all scenarios, giving little differentiation between the scenarios and yielding a relative large increase (27%-31%) compared to the increase modelled by MIRA.

In this study, we will make a stronger differentiation between the nature land-use claims for the different scenarios than in the WLO study. A key scenario-assumption is that in the A1 and A2-scenarios there will be significantly less attention for nature as compared to the B1 and B2-scenarios. This holds for the (lower) claim, as well as the protection status of currently protected (VEN) areas. In the Global Economy scenario, with its strong growth in welfare, the focus of nature will be in relation to recreation. In the A2 and B2-scenarios, on the other hand, the combination with agriculture is very important in order to not become too dependent on import of food. In the B1-scenario the focus is on preserving and strengthening the existing structure.

The land-use claim in absolute terms (i.e. hectares) is difficult to establish. As mentioned, the claim will be relatively high in the B1 and B2-scenarios as compared to the A1 and A2-scenarios. For the B1 and B2-scenarios we use a total land-use claim that is somewhat higher than the MIRA study (+15%), whilst in the A1 and A2-scenarios only a modest claim (+3%) is formulated. Moreover, the claims in the A1 and A2-scenarios will only apply for the class that represents the narrative best (i.e. recreation for A1, agriculture in A2). The other classes will get no claim, or even a Null claim, which implies that they are allowed to lose area in order to accommodate the other claims (Table 12).

Table 12. Total claim and differentiation between related nature classes.

	Change nature area	Total (ha)	Core Nature	Nature-agriculture	Nature-recreation	Nature-forestry
Present (ha)		503467	141169	195875	166176	246
Present (%)			28%	39%	33%	0%
A1	+3%	15000	0	Null	15000	0
A2	+3%	15000	Null	15000	Null	0
B1	+15%	75519	21175	29381	24926	37
B2	+15%	75519	26175	49307	0	37

5.2.4 Land-use claims agriculture

For agriculture, no claim is formulated, similar to the WLO study in the Netherlands. In all scenarios both cattle farming and crop production will be given a Null claim, implying that they can lose area in favour of other land uses for which claims are formulated. In the GE and TM-scenarios (and especially in the latter) there will be, however, also some nature classes with a Null claim. This means that the pressure on agricultural land will be less there, to the detriment of nature. Agricultural classes giving in area in favour for other land uses does not necessarily mean that the agricultural sector total production will shrink, as it can be countered by (further) intensification, concentration of the production processes or an increase in productivity due to technological advancement.

In contrast to cattle farming and crop production, horticulture will be given a (modest) land use claim. MIRA does not explicitly model horticulture, so cannot be used to formulate a land use claim. The claim for horticulture is derived from a report by Gavilan et al. (2006), which investigates the future of agriculture. Gavilan et al. (2006) explore four scenarios based on liberalisation and environmental policy. For horticulture, however, they do not differentiate between the four scenarios and use a linear extrapolation from 1990-2003 to project the area for horticulture in 2020. They calculated a 60% increase between 2002 and 2020. When such a trend (2.6% per year) is recalculated to a 25 year period (2005-2030), this would be an increase of about 90%. Therefore, we use a land-use claim of about 90% for horticulture land use (Table 13).

Table 13. Land use claim for horticulture.

	Change horticulture 1990-2003 (% per year)	CcASPAR horticulture (2030)	**CcASPAR land use claim horticulture (ha's)**
Present	+2.6%		**2661**
GE		+90%	**2395**
TM		+90%	**2395**
SE		+90%	**2395**
RC		+90%	**2395**

5.2.5 Total claims for 2030 and 2050

When combining the claims described in the previous subsections, the following land-use claim table can be compiled to feed into the land-use model (Table 14) for the projections of 2030. In the second column the current (2005) area of each land-use class is given. In the third to sixth column the land-use claim is given for each of the scenarios in absolute hectares, and in relative increase with respect to the current situation. The land-use claims for 2050 are derived from the 2030 claims by multiplying the land-use claims for 2030 with a factor 1.8. This factor is determined by linearly extrapolating the claims to 2050. The land-use claims for 2050 can be found in Annex A.

Table 14. Overview of all land-use claims in absolute terms (hectares) and change in relative terms (percent).

Land-use class	Current land use	A1	A2	B1	B2
Residential – high density	19443	10000	3394	10000	0
		+51%	+17%	+51%	0%
Residential – medium density	165092	35765	27950	35975	12790
		+22%	+17%	+22%	+8%
Residential – loose buildings & ribbons	50339	20000	8585	1000	6000
		+40%	+17%	+2%	+12%
Industrial	20682	5624	4127	3529	1134
		+27%	+20%	+17%	+5%
(non-)Commercial services	2732	849	641	557	224
		+31%	+23%	+20%	+8%
Horticulture	2661	2395	2395	2395	2395
		+90%	+90%	+90%	+90%
Cattle farming	118713				
		Null	Null	Null	Null
Agriculture	423541				
		Null	Null	Null	Null
Nature – Agriculture	195875		15000	29381	49307
		Null	+8%	+15%	+25%
Nature – Forestry	246	0	0	37	37
		0%	0%	+15%	+15%
Nature – Recreation	166176	15000		24926	0
		+9%	Null	+15%	0%
Core nature	141169	0		21175	26175
		0%	Null	+15%	+19%
Infrastructure (fixed)	38720	0	0	0	0
		0%	0%	0%	0%
Water bodies (fixed)	16225	0	0	0	0
		0%	0%	0%	0%

5.3 Suitability maps to drive the model

Various suitability maps are used to guide the allocation process in the model. These suitability maps can roughly be divided in policy maps, distance maps and physical maps. Physical maps are maps representing the physical condition of the land. In this case maps representing the soil and relief have been used. The relief map (Figure 6) is based on the 25 x 25 meter elevation model for Flanders. The relief calculated from this elevation map has been classified into four categories which represent increasingly steeper areas (<3%; 3-8%; 8-16%; >16%). Steep areas have an especially negative influence on the suitability of urban land uses, and to a lesser degree also on agriculture.

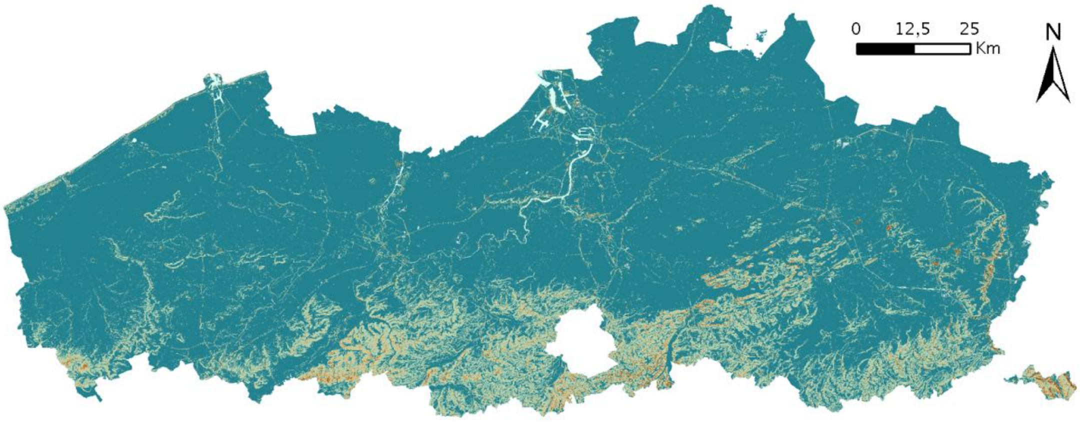

Figure 6. Relief suitability map for Flanders. The maps shows relief in four classes, ranging from relatively flat (dark blue), up to very steep (brown).

The soil map (Figure 7) is based on the *fysische systeemkaart* (Vlaamse Landmaatschappij, 2010) from which dominant soil classes have been extracted. These soil characteristics have been linked to suitability of natural and agricultural land uses. In these cases clayey soils have been given a better suitability for cattle breeding, loamy soils a better suitability for crop production and sand a better suitability for forestry. With respect to core nature and recreation, suitabilities have been kept equal as they relate to many different types of environments.

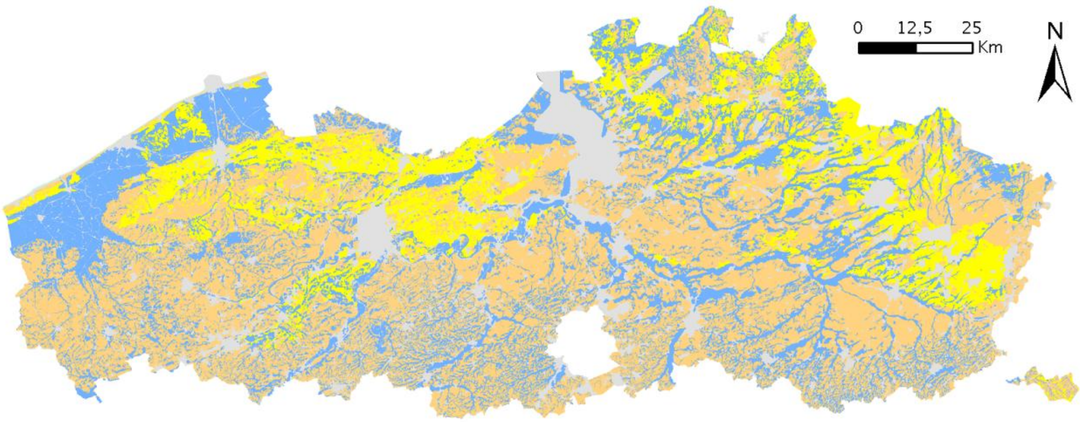

Figure 7. Soil map for Flanders. Blue colours denote a wet/clayey soil, yellow colours a sandy/dry soil and beige a loamy soil.

Distance maps included in the model are on the one hand maps representing the accessibility to work via motorways and trains, on the other hand maps representing the distance to ports and roads. The last one is mainly used to steer the allocation of residential ribbon developments, a typical feature of the Flemish urban landscape (Figure 8). Figure 9 shows the distance to a harbour (both sea and river), used to restrict the development of industrial areas outside the current main industrial areas. The distance to municipalities with over 250 employees per square kilometre, either restricted by the access via train or via road, are shown in respectively Figure 10 and 11. All distance maps are rescaled to a scale between 0 and 1, where 1 is very close and 0 far away. This is done to have the different maps more easily implemented into the Land Use Scanner and to be able to make consistent comparisons between the maps.

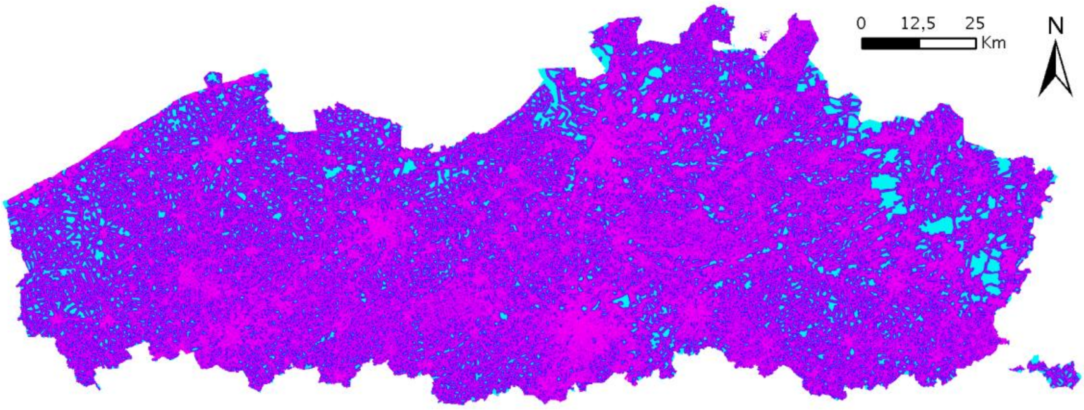

Figure 8. Distance to roads (purple close, light blue far away).

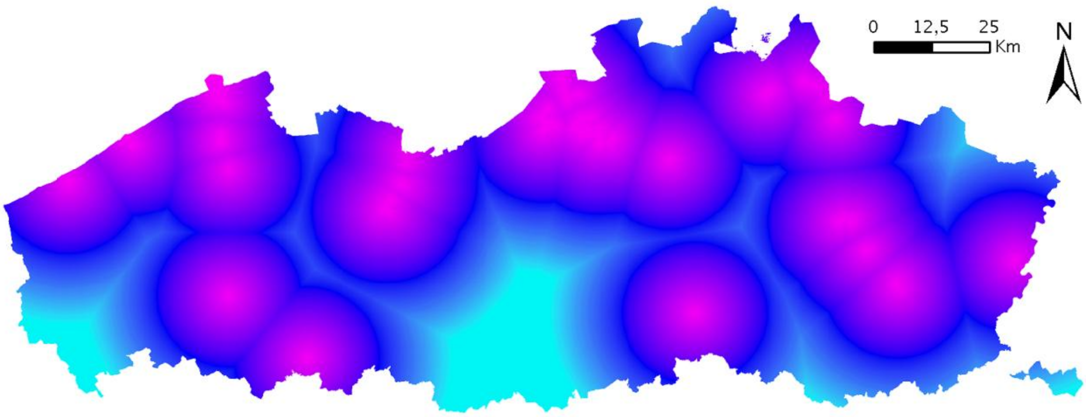

Figure 9. Distance to harbours (purple close, light blue far away).

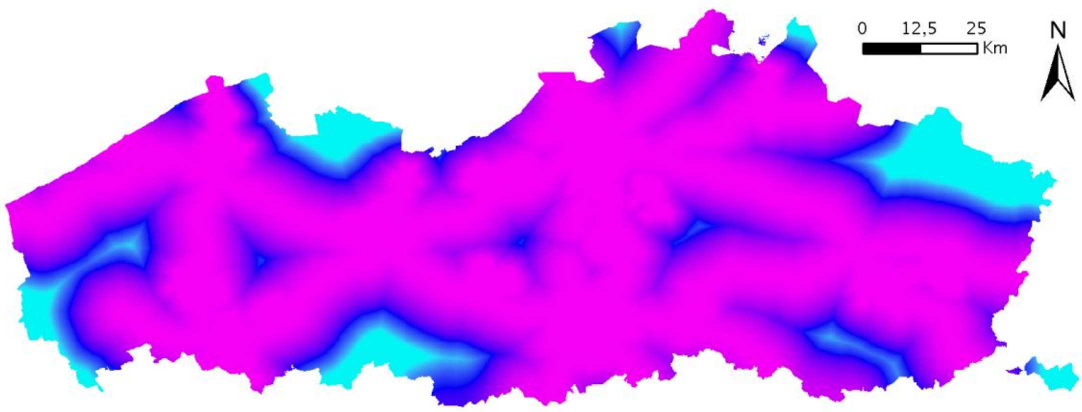

Figure 10. Distance to municipalities with a job density of over 250 employees per square kilometre, restricted by train (purple close, light blue far away).

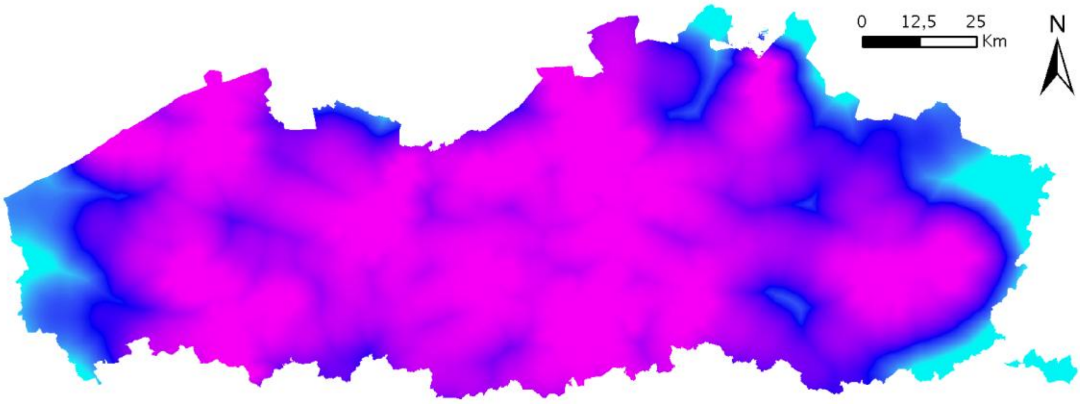

Figure 11. Distance to municipalities with a job density of over 250 employees per square kilometre, restricted by road (purple close, light blue far away).

Lastly, the policy maps represent the effect of specific policies aimed at preserving certain areas or guiding developments to certain areas. These include maps denoting protected nature areas (*VEN areas*), denoting cultural historic landscapes (*Ankerplaatsen*) and designated urban areas (*stedelijke gebieden*). The VEN areas (Figure 12) allow to differentiate the importance of natural areas between the different scenarios. For instance, in the A1 scenario the outlines of the VEN areas add little to the suitability of the grid cells for nature. In the B1 scenario on the other hand, these areas add considerably to the suitability of the cells for nature, and have a negative suitability for urban fabric.

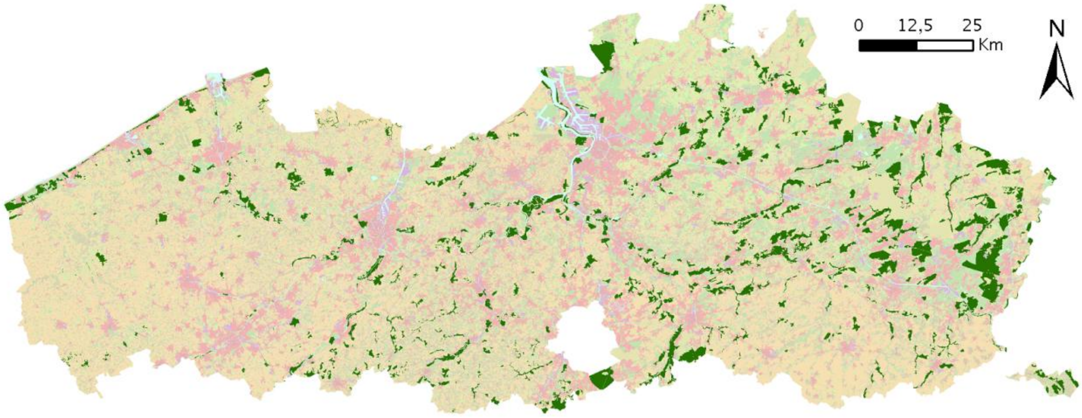

Figure 12. Map denoting the (VEN) areas in which nature has a protected status (dark green areas).

The *ankerplaatsen* (Figure 13) are areas which have been declared as traditional landscapes with a high cultural value. The effect of protection of these traditional landscapes is modelled by increasing the suitability of current land use of grid cells within these ankerplaatsen, meaning it's more difficult to change them. This is especially the case for the regional communities scenario in which cultural heritage is valued highly.

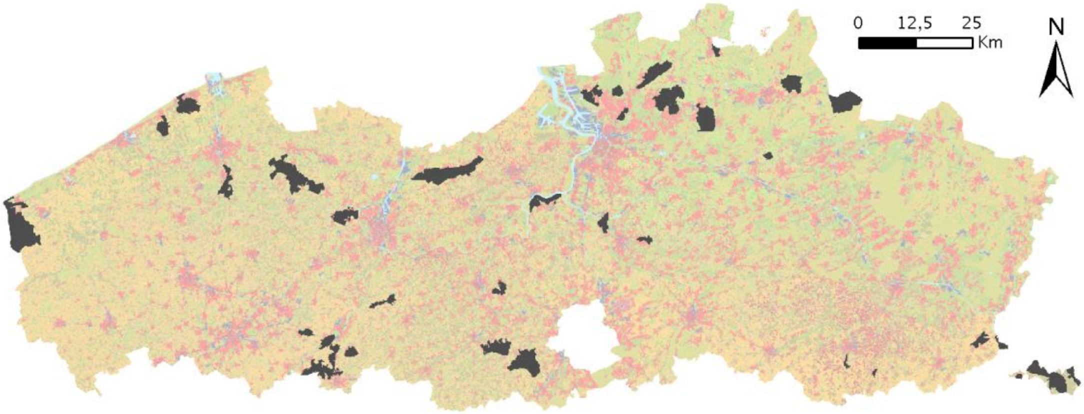

Figure 13. Map showing the ankerplaatsen (grey areas), which are areas of traditional landscapes with a high cultural value.

The urban areas are shown in Figure 14. These are areas that are specifically designated for urban fabric, and these are areas that will not likely lose their urban purpose. Current policy to reduce urban sprawl aims to develop most new houses in these areas. In the model, these areas are used to guide residential and other urban developments in the B-scenarios which are characterized by strong regulating governmental influence. In the A-scenarios the steering influence of these areas is much lower.

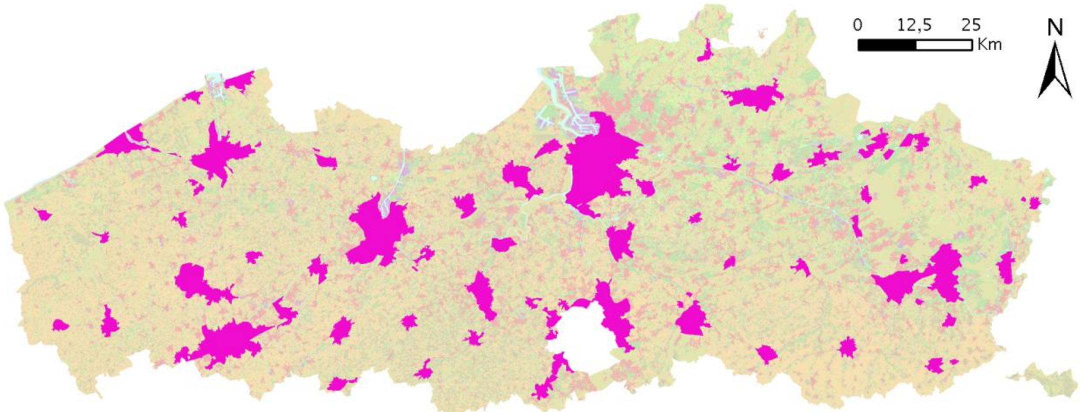

Figure 14. Maps of designated urban areas (purple).

Depending on the scenario, these suitability maps have been assigned weighting factors, as it is assumed that the importance of some of the different suitabilities may be different, depending on societal, economic and political developments. However, some physical suitabilities obviously will not change, as for instance slope and soil properties are not dependent on these processes. The exact weighing of the different suitability maps can be found in the tables found in Annex B.

6 Preliminary results and discussion

The results of the Land Use Scanner model for Flanders are presented in this chapter. These results, consisting of projections of future dominant land-use types, are shown below for the years 2030 and 2050. These projections are based on the scenarios for land-use claims, as described in previous chapters and represent a first iteration of the scenarios described in this report. Further refinement is possible through subsequent work; through adjustments to the socioeconomic scenarios on which these land-use projections are based, changes in weighting factors, as well as the exploration of the possibilities to insert certain adaptation measures in the land-use model. See Annex C for the corresponding amount of cells per land use for each scenario.

Before examining the future projections more closely, it is valuable to start with a comparison of the baseline land-use in Flanders for 2005 (Figure 16) with the land-use map for 2005 created by Gobin et al. (2009) (Figure 15). A couple of differences can be noticed. First, we see a slight difference in residential land use at the coast of Flanders. For example, the land-use map in Gobin et al. shows somewhat more built-up area in the coastal area around De Panne and Kokszijde compared to the land-use map used in this study. Second, the land-use map in Gobin et al. shows larger areas of industrial and commercial areas around the harbours. A main reason for this difference might be the lower spatial resolution in Gobin et al. (150 x 150 meter for Gobin et al. versus 50 x 50 meter for the land-use maps used in this study). The higher spatial resolution in this study results in more detail, showing for example nature or agricultural area between port industries, which are too small to be seen on a lower spatial resolution. Finally, the maps provided in Gobin et al. show a greater differentiation in nature areas, whereas this study is more differentiated in residential areas.

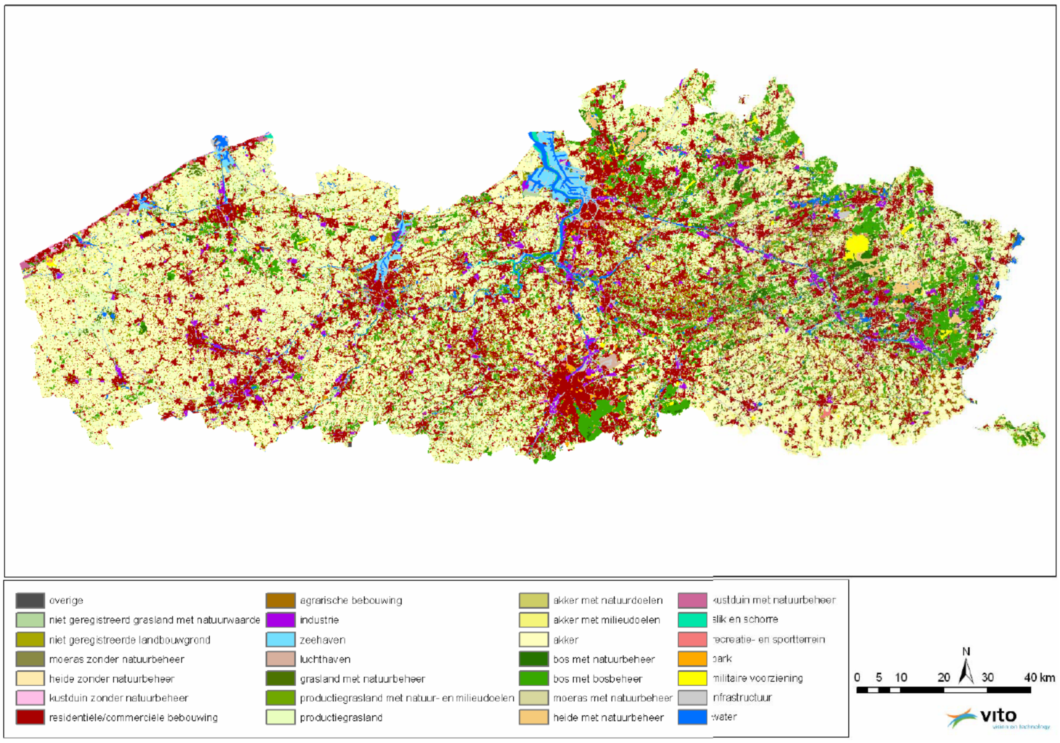

Figure 15. Land-use map created by Gobin et al. (year: 2005)

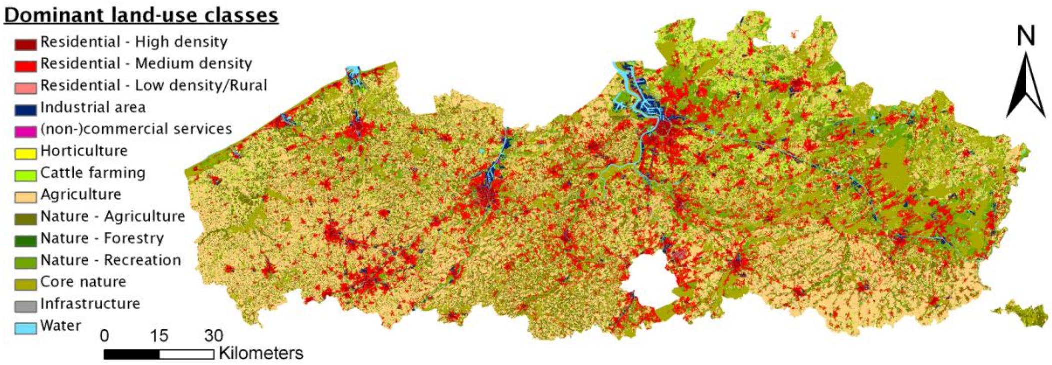

Figure 16. Baseline land-use in Flandres (year: 2005)

6.1 Projections for 2030

Overall, the projections show large expansions for residential areas in Flanders, and this is valid for all three classes of residential areas, and under all four scenarios. Also industry and services expand under all scenarios. Expansion of these classes is expressed in considerable expansions of urban areas, as is indicated in the four scenarios, compared to the baseline land-use in 2005 (Figure 16). These classes are indicated by red-purple colours. The expansion is mainly occurring in the triangle Brussels-Antwerp-Ghent. Core nature expands in the B-type scenarios of Strong Europe and Regional Communities, indicated by the brown-green colours. Table 14 and Table C.1 provide more detail to the exact distribution of land use by 2030 across the different classes.

When zoomed in on the projected land-use maps for the A-scenarios (Figure 17 and 18), a few notable remarks can be made. For starters, we see in these scenarios a typical pattern of urban sprawl occurring, as expected in these scenarios (see Section 5.2.1). This pattern is the most visible in the outskirts of Bruges, Antwerp and Kortrijk, where new residential areas are build in former pastures and cropland. We also see a relatively strong increase in ribbon development, as expected with urban sprawl. Second, we see a large increase in recreational nature areas, particularly in the coastal areas at the expense of core nature areas, but also at the expense of pastures and cropland around the larger cities. Finally, if we compare the differences in residential areas with the accessibility to work suitability maps, we see that the expansion of residential areas almost everywhere occurred in areas with a high accessibility to work.

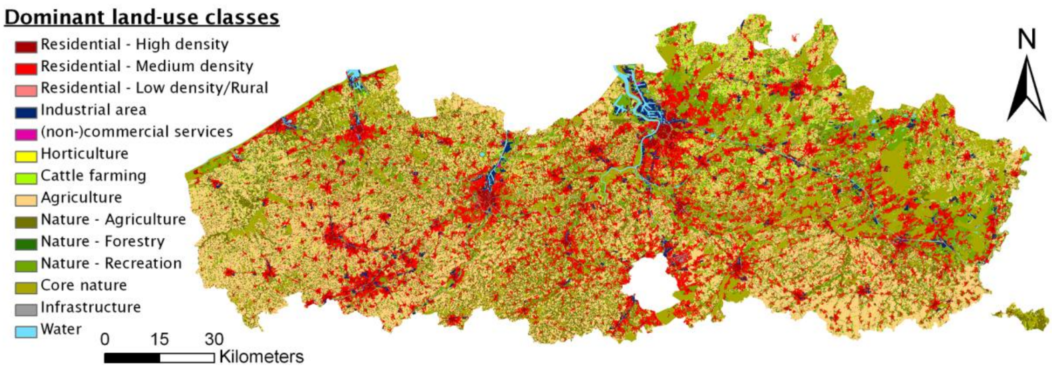

Figure 17. Projected land-use in Flanders, according to the Global Economy/A1 scenario (2030).

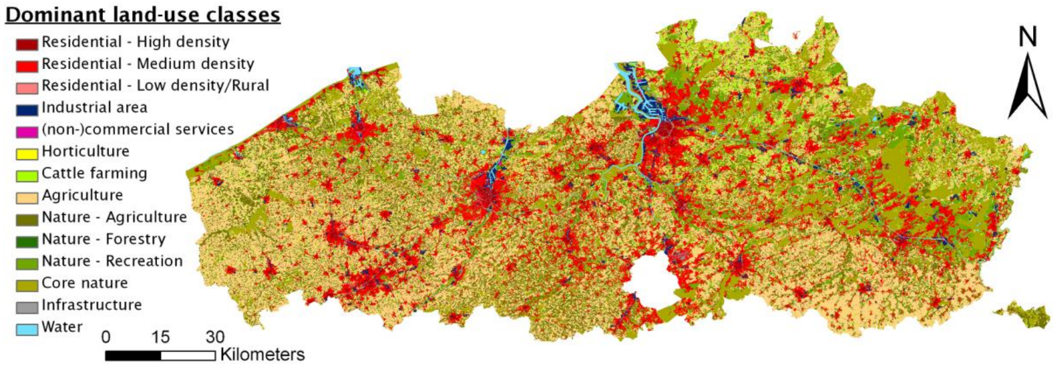

Figure 18. Projected land-use in Flanders, according to the Transatlantic Markets/A2 scenario (2030).

If we look at the projected land-use maps for the B-scenarios (Figure 19 and 20), we see a couple of differences compared to the A-scenarios. At first, we see a higher density in the big cities, such as Antwerp, Ghent and Kortrijk. This is in line with the calculations made in Section 5.2.1, where it is expected that strict policy rules in the B-scenarios prevent urban sprawl. Cities now only expand in the designated urban areas, as defined in Figure 12.

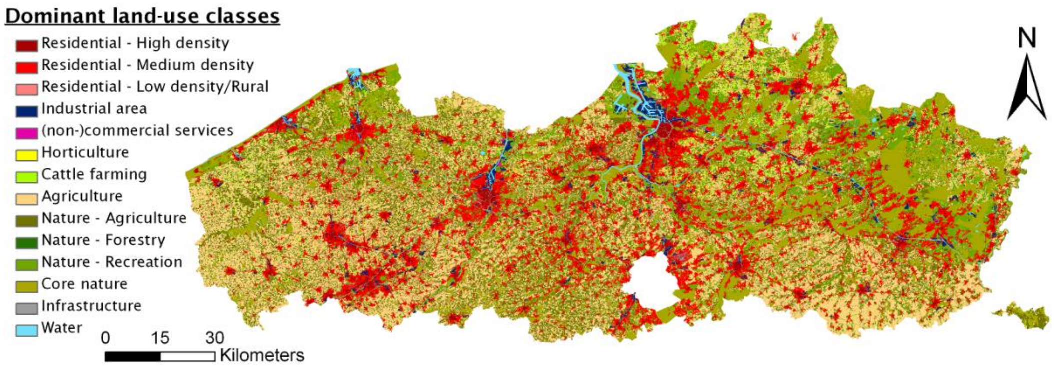

Figure 19. Projected land-use in Flanders, according to the Strong Europe/B1 scenario (2030).

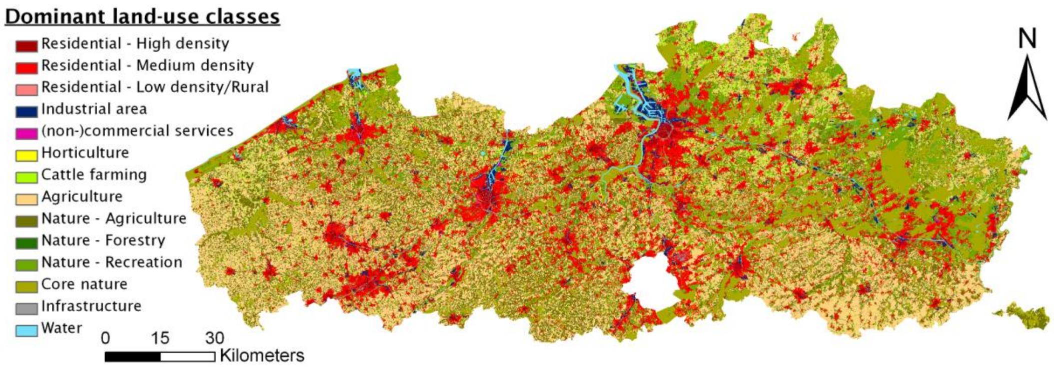

Figure 20. Projected land-use in Flanders, according to the Regional Communities/B2 scenario (2030).

Second, in the B-scenarios there is more nature area in previous pastures and cropland, which can also be observed in Table C.1 in Annex C. In Table C.1 we can see that normal agricultural area decreases, but nature agricultural area increases. This is the most visible in the eastern part of Flanders and in the north-west near Zeebrugge. This is due to the higher importance of nature areas in these scenarios. Third, in the Regional Communities scenario, there is no increase in the high density residential areas compared to the baseline land-use in Flanders. Due to the relatively low population growth and high valuation of local communities, people prefer not to live in dense cities, but prefer living in less dense semi-rural settings.

6.2 Projections for 2050

The projections for 2050 follow in general the same lines as the projections for the year 2030, but are extrapolated by another 20 years. Table C.2 provides more detail to the exact distribution of land use by 2050 across the different classes. It should be noted that the simple extrapolation of socioeconomic information is only intended for illustration and does not rely anymore on the original socioeconomic projections from MIRA and WLO, that the 2030 scenarios presented here are based on.

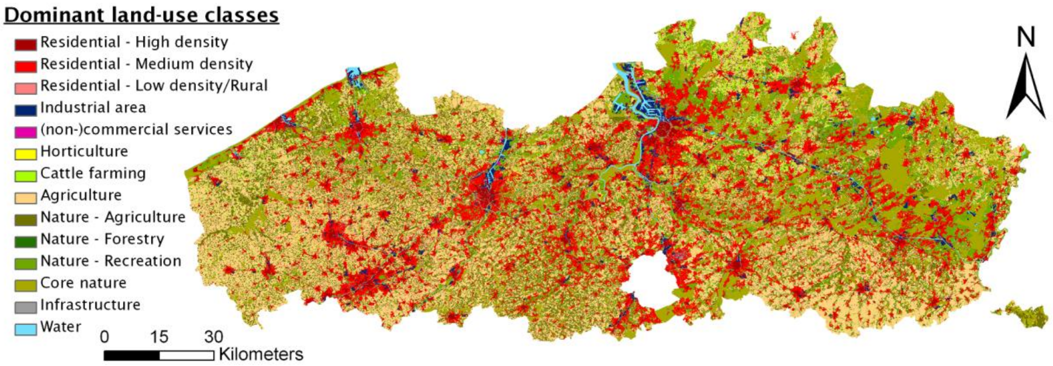

Figure 21. Projected land-use in Flanders, according to the Global Economy/A1 scenario (2050).

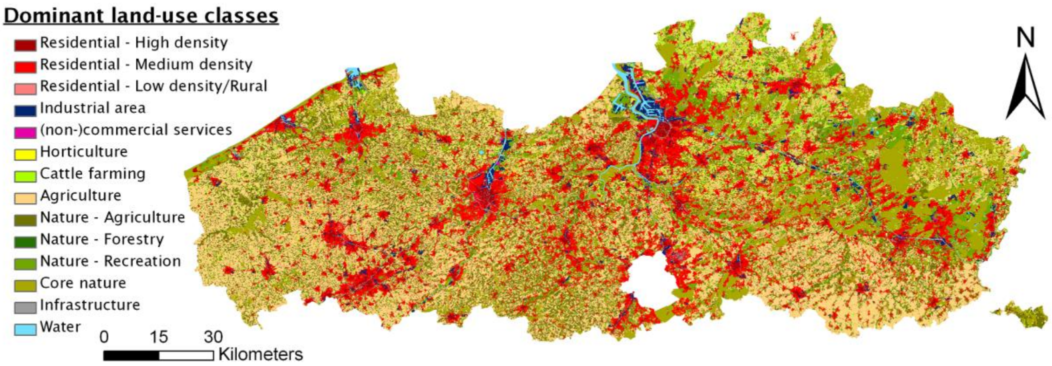

Figure 22. Projected land-use in Flanders, according to the Transatlantic Markets/A2 scenario (2050).

Figures 21 and 22 show that the trends occurring in the A-scenario projections for 2030, are the same for the projections of 2050. There is again a continued expansion of residential area and recreational area in both scenarios, mainly around the big cities. Interesting is the large increase in industrial area in the ports of Antwerp and Zeebrugge. A reason might be the restricted expansion for the industrial sector to areas which are close to harbours (see Figure 9). For the B-scenarios (see Figures 23 and 24), two things can be observed. First, especially in the Strong Europe scenario, there is an even stronger clustering of urban areas. Second, more agricultural area is turned into nature (see Table C.1). The latter is mainly the case in the most eastern part of Flanders and around residential areas in the rest of Flanders.

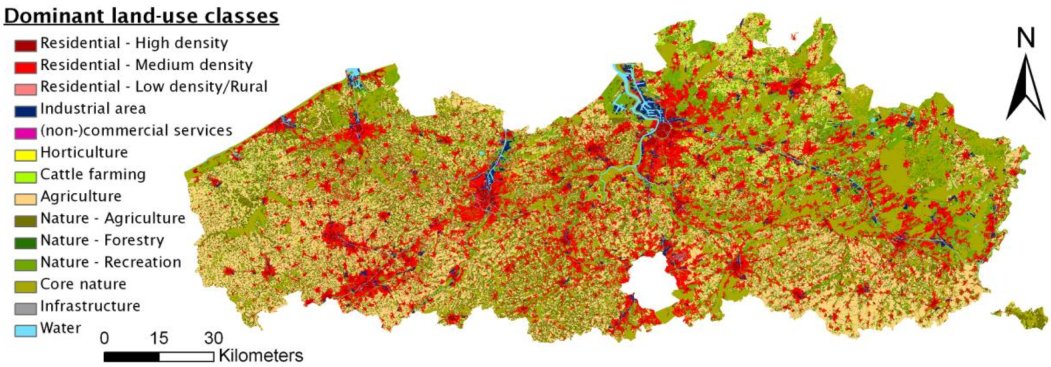

Figure 23. Projected land-use in Flanders, according to the Strong Europe/B1 scenario (2050).

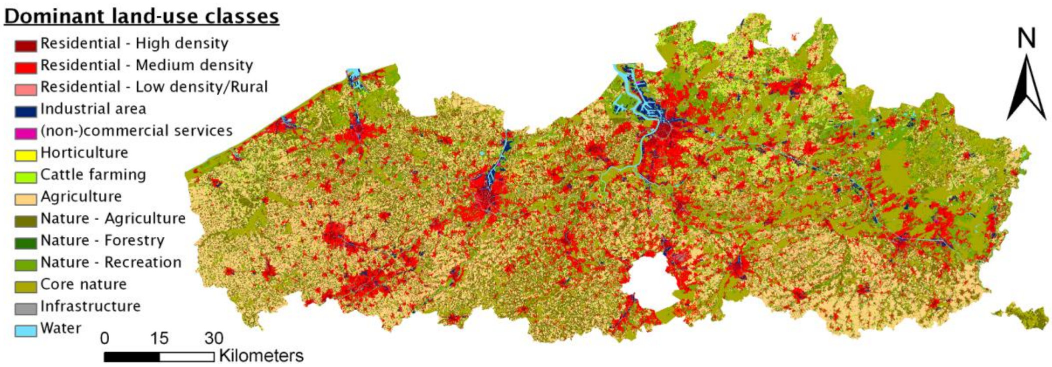

Figure 24. Projected land-use in Flanders, according to the Regional Communities/B2 scenario (2050).

6.3 Limitations of the model

The land-use projections presented in this report are based on a series of sources, and therefore provide a well-supported illustration of ranges of potential future land use that will determine many socioeconomic and environmental interactions by the year 2030 and 2050. This information can be used specifically to assess future vulnerability to climate changes, as well as possible (spatial) adaptation options and strategies.

The projections derived from the Land Use Scanner model for Flanders, however, have a number of limitations. Importantly, it has proved difficult to get a detailed and correct baseline land-use map for 2005. This is mainly due to the fact that Flanders has a complex landscape and some data to approach this complexity had to be derived from different sources, both vector and raster, some of which is known to be outdated, and which are all combined into one land-use map for Flanders. This results in a couple of errors, such as some residential area in the port of Zeebrugge and Antwerp, cottages near the coast which are defined as residential area and agricultural area around cities which should now be built-up area. The first two are the result of combining different maps, whereas the last error is due to outdated data. Furthermore, because of aggregation of highly detailed land-use data, it is also unavoidable that some ambiguity arises over the exact nature of a specific land-use class. For instance, there is a high heterogeneity in classes like agriculture (fruit trees, grains), nature (many types) and services (public services and businesses). Also green areas (e.g., parks, vegetable gardens, cemeteries) within the city have been aggregated with the residential classes.

Second, when projecting future land use, the model ‘steers’ with the use of suitability maps where the land-use claims should be allocated. This allocation is, however, very sensitive to changes in the suitability maps. Therefore, it is often quite difficult to obtain a land-use projection that perfectly follows intended policies that are associated with the scenarios. For example, in the B-scenarios, a clustering of urban areas and more nature area is expected due to strict policy rules in these areas. When these strict policy rules are ‘implemented’ in the model, we see indeed more clustering of urban areas and more nature area. However, to realize this, the model completely reallocates villages from the country side to the big cities and changes these villages into nature area.

Finally, most of the numbers in the scenarios are simply linearly extrapolated projections for the future, based on historical data. For 2030, it is not directly a problem that it is linearly extrapolated, but for the projections for the year 2050 it may give a somewhat less realistic projection of the future. Therefore these projections should be used with great caution, as they are mere illustrations and not rooted in the underlying socioeconomic basis that MIRA and WLO provide.

For the upcoming 20 years, we can probably assume that the economy will roughly develop as it did the last 20 years, but for the upcoming 40 years it will be more difficult to project. For example, the European economy is currently in a recession, resulting in growth rates that are much lower than the previous years. For the upcoming years, we could probably still have an average growth rate that is the same as the last years. However, for the period between 2030 and 2050 it is much harder to predict how the growth rates in Europe will develop. Growth rates could either decrease or increase more than expected. Nevertheless, by providing the four different scenarios with different growth rates, we somewhat account for this problem.

7 Conclusions

This report has presented the setup of the Land Use Scanner configuration for Flanders, its components (storylines, spatial claims and weights of suitability) and preliminary results, for four socioeconomic scenarios; Global Economy (A1), Transatlantic Markets (A2), Strong Europe (B1), and Regional Communities (B2).

The land-use projections based on these four socioeconomic scenarios in land-use projections for the years 2030 and 2050 provide the expected spatial patterns as defined in the scenarios and narratives. For example, the land-use projections based on the A-scenarios show a typical pattern of urban sprawl occurring and a strong increase in the typical Flemish ribbon development, as expected in these scenarios. This pattern is the most visible in the outskirts of Bruges, Antwerp and Kortrijk, where new residential areas are build in former pastures and cropland. In contrast, the B-scenarios show much denser residential areas, which is expected with more strict policy rules for building outside existing urban areas. Second, we see in the A-scenarios a large increase in recreational nature areas. This increase occurs not only in the coastal areas at the expense of core nature areas, but also at the expense of pastures and cropland around the larger cities. Finally, we see especially in the projections of 2050 for the Global Economy scenario a large increase in industrial areas in and around the port regions. This is in line with the large increase in global trade that is expected in these scenarios.

In all scenarios we see an increase in built-up area, ranging from a large increase in the Global Economy scenario to a relative small increase in the Regional Communities scenario. Still, in all future scenarios we see a stronger pressure on the available land, varying from the need for residential area in the more trade-oriented scenarios, to the need to preserve nature area in the somewhat more self-sufficient scenarios.

While the land-use projections provide a useful illustration of future land-use according to a range of possible storylines, they also have some shortcomings. First, it was difficult to create a land-use map for the base year, due to outdated data and the large variety of data sources that was used to create the map. Second, the allocation of land-use claims is very sensitive to adjustments made to the suitability maps, resulting in sometimes unwanted results. Third, the linear extrapolation of the land-use claims may not be the best approach for projections for the more distant period up to 2050, as it is hard to project how the economy and population will develop in the upcoming 40 years.

Nevertheless, this study provides a basis for a better insight in the possible land-use patterns that will occur in the future. These land-use projections are not only valuable for assessing changes in and around large municipalities such as Antwerp and Ghent, but also for a smaller municipality such as De Panne. These types of future land-use projections help us to better understand spatial land-use allocation, form a basis for the assessment of potential climate change impacts, and provide discussion material for regional planning and guidance for the implementation of climate adaptation measures.

More specifically, land-use maps calculated in models such as the Land Use Scanner can be a good starting point for the implementation of climate adaptation measures. For example, land-use maps can be used in flood risk and drought risk assessments when information on the hazard (drought, flood) is combined with future changes in exposure (land-use) and vulnerability (based on socioeconomic parameters from the different scenarios). Also, the land-use maps can help to develop and assess different types of adaptation measures, such as flood-risk zoning and compartmentalisation.

It is expected that this model setup will be fine-tuned in consultation with the other researchers within the CcASPAR project. There is a variety of options available for experiments. Possible applications of the model and/or its results include:

- More detailed incorporation of dynamics in case study areas like the Kempen;
- Assessing the effect of spatial regulation outside flood-prone zones in the coastal region of Flanders;
- Including land-use change scenarios in flood damage estimates;
- Assessing the effect of certain spatial planning policies, such as polycentric spatial policy;
- Including land-use projections in hydrological modelling.

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Annex A Land-use claims 2050

Land-use class	Current land use	A1	A2	B1	B2
Residential – high density	19443	18000 93%	6109,2 31%	18000 93%	0 0%
Residential – medium density	165092	64377 39%	50310 30%	64755 39%	23022 14%
Residential – loose buildings & ribbons	50339	36000 72%	15453 31%	1800 4%	10800 21%
Industrial	20682	10122,92 49%	7428,994 36%	6351,425 31%	2041,149 10%
(non-)Commercial services	2732	1527,875 56%	1153,055 42%	1003,128 37%	403,4169 15%
Horticulture	2661	4311 162%	4311 162%	4311 162%	4311 162%
Cattle farming	118713	Null	Null	Null	Null
Agriculture	423541	Null	Null	Null	Null
Nature – Agriculture	195875	Null	27000 14%	52885,8 27%	88752,6 45%
Nature – Forestry	246	0 0%	0 0%	66,6 27%	66,6 27%
Nature – Recreation	166176	27000 16%	Null	44866,8 27%	0 0%
Core nature	141169	0 0%	Null	38115 27%	47115 33%
Infrastructure (fixed)	38720	0 0%	0 0%	0 0%	0 0%
Water bodies (fixed)	16225	0 0%	0 0%	0 0%	0 0%

Annex B Weighting of suitability maps

Table B.1 Global Economy/A1

		Policy			Distance					Physical			
	Current LU*	Ankerplaatsen**	VEN	Stedelijk	dist_haven	dist_straat	toegang_werk_OV	toegang_werk_auto	geluid	klei	leem	zand	slope
Residential - high density	6,5	0,0	-2,0	4,0	0,0	2,0	3,0	3,0	-2,0	0,0	0,0	0,0	-4,0
Residential - medium density	2,3	0,0	-2,0	4,0	0,0	3,0	4,0	4,0	-2,0	0,0	0,0	0,0	-4,0
Residential - loose buildings & ribbons	1,3	0,0	-3,0	0,0	2,0	5,0	2,0	2,0	-2,0	0,0	0,0	0,0	-2,0
Industrial	3,8	0,0	-2,0	1,0	5,0	0,0	2,0	2,0	0,0	0,0	0,0	0,0	-2,0
(non-)Commercial services	3,7	0,0	-2,0	3,0	3,0	1,0	3,0	3,0	0,0	0,0	0,0	0,0	-3,0
Horticulture	3,7	0,0	-2,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	-2,0
Cattle farming	2,0	0,0	-1,0	-2,0	0,0	0,0	0,0	0,0	0,0	3,0	1,0	0,0	0,0
Agriculture	2,0	0,0	-1,0	-2,0	0,0	0,0	0,0	0,0	0,0	1,0	3,0	0,0	0,0
Nature - Agriculture	3,0	0,0	1,0	-2,0	0,0	0,0	0,0	0,0	-1,0	1,0	3,0	0,0	0,0
Nature - Forestry	3,0	0,0	2,0	-2,0	0,0	0,0	0,0	0,0	-1,0	0,0	2,0	2,0	0,0
Nature - Recreation	1,3	0,0	2,0	1,0	0,0	0,0	0,0	0,0	-1,0	2,0	2,0	2,0	0,0
Core nature	2,0	0,0	4,0	-2,0	0,0	0,0	0,0	0,0	-1,0	2,0	2,0	2,0	0,0
Infrastructure (fixed)													
Water bodies (fixed)													

All maps are scaled between 0-1 and multiplied with coefficient

*Current land-use is applied using LN(100*Ratio)
**The Ankerplaatsen increase the suitability of current landuse by increasing the multiplication factor of the LN(100*Ratio), which is normally 1.

Table B.2 Transatlantic Markets/A2		Policy			Distance					Physical			
	Current LU*	Ankerplaatsen**	VEN	Stedelijk	dist_haven	dist_straat	toegang_werk_OV	toegang_werk_auto	geluid	klei	leem	zand	slope
Residential - high density	2,3	0,5	-2,0	4,0	0,0	2,0	3,0	3,0	-2,0	0,0	0,0	0,0	-4,0
Residential - medium density	1,3	0,5	-2,0	4,0	0,0	3,0	4,0	4,0	-2,0	0,0	0,0	0,0	-4,0
Residential - loose buildings & ribbons	1,2	0,5	-3,0	0,0	0,0	5,0	2,0	2,0	-2,0	0,0	0,0	0,0	-2,0
Industrial	2,5	0,5	-2,0	1,0	5,0	0,0	2,0	2,0	0,0	0,0	0,0	0,0	-2,0
(non-)Commercial services	2,4	0,5	-2,0	3,0	3,0	1,0	3,0	3,0	0,0	0,0	0,0	0,0	-3,0
Horticulture	2,9	0,0	-2,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	-2,0
Cattle farming	2,0	0,0	-1,0	-2,0	0,0	0,0	0,0	0,0	0,0	3,0	1,0	0,0	0,0
Agriculture	2,0	0,0	-1,0	-2,0	0,0	0,0	0,0	0,0	0,0	1,0	3,0	0,0	0,0
Nature - Agriculture	2,3	0,0	1,0	-2,0	0,0	0,0	0,0	0,0	-1,0	1,0	3,0	0,0	0,0
Nature - Forestry	3,0	0,0	2,0	-2,0	0,0	0,0	0,0	0,0	-1,0	0,0	2,0	2,0	0,0
Nature - Recreation	1,3	0,0	2,0	1,0	0,0	0,0	0,0	0,0	-1,0	2,0	2,0	2,0	0,0
Core nature	2,0	0,0	4,0	-2,0	0,0	0,0	0,0	0,0	-1,0	2,0	2,0	2,0	0,0
Infrastructure (fixed)													
Water bodies (fixed)													

All maps are scaled between 0-1 and multiplied with coefficient

*Current land-use is applied using LN(100*Ratio)
**The Ankerplaatsen increase the suitability of current landuse by increasing the multiplication factor of the LN(100*Ratio), which is normally 1.

Table B.3 Strong Europe/B1

		Policy			Distance					Physical			
	Current LU*	Ankerplaatsen**	VEN	Stedelijk	dist_haven	dist_straat	toegang_werk_OV	toegang_werk_auto	geluid	klei	leem	zand	slope
Residential – high density	6,4	2,0	-4,0	4,5	0,0	1,0	3,0	3,0	-2,5	0,0	0,0	0,0	-4,0
Residential – medium density	2,0	2,0	-4,0	4,0	0,0	1,0	4,0	4,0	-2,5	0,0	0,0	0,0	-4,0
Residential – loose buildings & ribbons	1,0	3,0	-3,0	0,0	0,0	5,0	2,0	2,0	-2,5	0,0	0,0	0,0	-2,0
Industrial	2,9	3,0	-4,0	2,0	5,0	1,0	2,0	2,0	0,0	0,0	0,0	0,0	-2,0
(non-)Commercial services	3,2	3,0	-3,0	3,0	3,0	1,0	2,0	2,0	0,0	0,0	0,0	0,0	-3,0
Horticulture	3,1	3,0	-2,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-2,0
Cattle farming	1,0	2,0	0,0	-1,0	0,0	0,0	0,0	0,0	0,0	3,0	1,0	0,0	0,0
Agriculture	1,0	2,0	0,0	-1,0	0,0	0,0	0,0	0,0	0,0	1,0	3,0	0,0	0,0
Nature – Agriculture	1,5	3,0	3,0	-1,0	0,0	0,0	0,0	0,0	-1,0	1,0	3,0	0,0	0,0
Nature – Forestry	3,5	3,0	3,0	-1,0	0,0	0,0	0,0	0,0	-1,0	0,0	2,5	2,5	0,0
Nature – Recreation	1,1	3,0	3,5	1,0	0,0	0,0	0,0	0,0	-1,0	2,0	2,0	2,0	0,0
Core nature	2,7	3,0	4,0	0,5	0,0	0,0	0,0	0,0	-2,0	2,0	2,0	2,0	0,0
Infrastructure (fixed)													
Water bodies (fixed)													

All maps are scaled between 0-1 and multiplied with coefficient

*Current land-use is applied using LN(100*Ratio)
**The Ankerplaatsen increase the suitability of current landuse by increasing the multiplication factor of the LN(100*Ratio), which is normally 1.

Table B.4 Regional Communities/B2

		Policy			Distance					Physical			
	Current LU*	Ankerplaatsen**	VEN	Stedelijk	dist_haven	dist_straat	toegang_werk_OV	toegang_werk_auto	geluid	klei	leem	zand	slope
Residential – high density	1,6	3,0	-4,5	4,5	0,0	1,0	3,0	3,0	-2,5	0,0	0,0	0,0	-4,0
Residential – medium density	3,0	3,0	-4,5	4,0	0,0	1,0	4,0	4,0	-2,5	0,0	0,0	0,0	-4,0
Residential – loose buildings & ribbons	2,5	3,0	-3,0	3,0	0,0	5,0	2,0	2,0	-2,5	0,0	0,0	0,0	-2,0
Industrial	1,8	3,0	-4,0	2,0	5,0	1,0	2,0	2,0	0,0	0,0	0,0	0,0	-2,0
(non-)Commercial services	1,9	3,0	-3,0	3,0	3,0	1,0	2,0	2,0	0,0	0,0	0,0	0,0	-3,0
Horticulture	2,8	3,0	-2,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-2,0
Cattle farming	1,0	2,0	0,0	-1,0	0,0	0,0	0,0	0,0	0,0	3,0	1,0	0,0	0,0
Agriculture	1,0	2,0	0,0	-1,0	0,0	0,0	0,0	0,0	0,0	1,0	3,0	0,0	0,0
Nature – Agriculture	1,4	3,0	3,0	-1,0	0,0	0,0	0,0	0,0	-1,0	1,0	3,0	0,0	0,0
Nature – Forestry	3,4	3,0	3,0	-1,0	0,0	0,0	0,0	0,0	-1,0	1,0	2,5	2,5	0,0
Nature – Recreation	0,7	3,0	3,5	1,0	0,0	0,0	0,0	0,0	-1,0	2,0	2,0	2,0	0,0
Core nature	2,8	3,0	4,0	0,5	0,0	0,0	0,0	0,0	-2,0	2,0	2,0	2,0	0,0
Infrastructure (fixed)													
Water bodies (fixed)													

All maps are scaled between 0-1 and multiplied with coefficient

*Current land-use is applied using LN(100*Ratio)
**The Ankerplaatsen increase the suitability of current landuse by increasing the multiplication factor of the LN(100*Ratio), which is normally 1.

Annex C Amount of future land-use per scenario

Table C.1 Land use in 2030	Reference LU	A1		A2		B1		B2	
	Amount of hectare	Amount of hectare	% change	Amount of hectare	% change	Amount of hectare	% change	Amount of hectare	% change
Residential - high density	22630	33816	149%	26416	117%	34333	152%	22513	99%
Residential - medium density	187306	228580	122%	219066	117%	229044	122%	201814	108%
Residential - loose buildings & ribbons	51040	71114	139%	59090	116%	51421	101%	66989	131%
Industrial	21294	27415	129%	25655	120%	25011	117%	22589	106%
(non-)Commercial services	1876	2497	133%	2272	121%	2167	116%	2073	110%
Horticulture	2518	4919	195%	4759	189%	4744	188%	4771	189%
Cattle farming	115473	73711	64%	91500	79%	65273	57%	73036	63%
Agriculture	427403	368105	86%	411454	96%	338204	79%	357068	84%
Nature - Agriculture	203077	208952	103%	219876	108%	235845	116%	255128	126%
Nature - Forestry	249	238	96%	248	99%	292	117%	289	116%
Nature - Recreation	161018	176310	109%	130712	81%	185974	115%	161094	100%
Core nature	145060	144227	99%	147910	102%	167170	115%	171012	118%
Infrastructure (fixed)	6660		FIXED		FIXED		FIXED		FIXED
Water bodies (fixed)	15106		FIXED		FIXED		FIXED		FIXED
Exterior area (fixed)	795992		FIXED		FIXED		FIXED		FIXED

Table C.2 Land use in 2050	Reference LU	A1		A2		B1		B2	
	Amount of hectare	Amount of hectare	% change	Amount of hectare	% change	Amount of hectare	% change	Amount of hectare	% change
Residential - high density	22630	34226	151%	26904	119%	34644	153%	21958	97%
Residential - medium density	187306	241333	129%	236181	126%	244994	131%	207828	111%
Residential - loose buildings & ribbons	51040	84303	165%	65507	128%	52707	103%	71623	140%
Industrial	21294	28484	134%	26934	126%	25856	121%	22724	107%
(non-)Commercial services	1876	2346	125%	2226	119%	2038	109%	2106	112%
Horticulture	2518	5420	215%	5360	213%	5109	203%	5336	212%
Cattle farming	115473	66239	57%	85491	74%	54031	47%	64581	56%
Agriculture	427403	343749	80%	395679	93%	303620	71%	330828	77%
Nature - Agriculture	203077	205391	101%	229506	113%	248872	123%	281383	139%
Nature - Forestry	249	234	94%	245	99%	300	121%	294	118%
Nature - Recreation	161018	185617	115%	117754	73%	197998	123%	156253	97%
Core nature	145060	142354	98%	147011	101%	169269	117%	173430	120%
Infrastructure (fixed)	6660		FIXED		FIXED		FIXED		FIXED
Water bodies (fixed)	15106		FIXED		FIXED		FIXED		FIXED
Exterior area (fixed)	795992		FIXED		FIXED		FIXED		FIXED