# Landscape level simulation of land use change

Peter H. Verburg, Martha Bakker, Koen P. Overmars, Igor Staritsky

Wageningen University, Wageningen, the Netherlands

## Abstract

Land use changes are a result of decision making at the local level which is influenced by changes in the regional and global economy, demography, policies and other factors operating over a wide range of organisational levels and spatial scales. This chapter describes a methodology to integrate the demands for changes in land use as determined by global and national scale processes with local level conditions influencing land use conversions across the European Union. The approach enables an assessment of landscape level changes in land use and the analysis of policies specifically aimed at land use and landscape functioning. A baseline scenario is presented to illustrate the approach and results.

## Keywords

Land use, Europe, spatial analysis, simulation, landscape change

## 1 Introduction

Changes in demography, demand for agricultural products and space for housing and industry, global trade and economic development are important factors that potentially lead to large changes in landscapes, not only through the conversion of land use, but as well through the modification of the farming intensity and structure. These changes can be stimulated or counteracted by policies aimed at the agricultural sector, nature protection or directly aimed at spatial planning of land use, for example the planning of compact urbanization. The likely impacts of these developments and policies on environment, landscapes and rural livelihoods are largely unknown. As policy makers need to act in an anticipative or pro-active manner they need to be informed timely on what will or could happen and on what may be done to lessen risks and to stimulate promising developments. Different types of research that potentially support policy makers in the identified challenges are available (Bennett et al., 2003). Research may aim at designing solutions for specific problems by calculating the optimal land use allocation given a set of objectives (Loonen et al., 2006; Matthews et al., 2006; Seppelt and Voinov, 2002; van Ittersum et al., 2004). Such studies may be used to determine optimal locations for urban development or intensive agriculture to minimize negative impacts on other land use functions. Other studies aim at the evaluation of the consequences of specific policies on land use (Britz et al., 2002; Meijl and Tongeren, 2002; Rounsevell et al., 2006a; Verburg et al., 2006a). The latter type of research aims at the evaluation of policy decisions and can therefore provoke policy discussions on the intended and un-intended effects of such policies and their alternatives. The SENSOR project, described in this book, aims at this type of policy support on land use change.

Because it is likely that the policy impact depends on change in demography, economy and other factors as well, it is needed to test the effects of the policies under different scenarios. Such scenarios are a means to capture some of the uncertainty in development of the main driving factors of the land use system. Scenarios have therefore become an important tool in policy support studies (Peterson et al., 2003; Rotmans et al., 2000; Wester-Herber, 2004; Xiang and Clarke, 2003). In the SENSOR project three scenarios are used that differ in assumed growth rates of economy and demography (Kuhlman, 2008).

Many scenarios studies, including a quantitative assessment for policy support, have been conducted in recent years (Busch, 2006), e.g. the climate change related studies of the Intergovernmental Panel on Climate Change (Arnell et al., 2004; IPCC, 2000), the Global Environmental Outlook (UNEP, 2002) and the Millennium Ecosystem Assessment (MEA, 2005). However, in most of these studies the spatial resolution of analysis is limited to 50x50 kilometre due to the dependence on global scale models (Strengers et al., 2004). Also the European assessment by the Advanced Terrestrial Ecosystem Analysis and Modelling project (Rounsevell et al., 2005; Schröter et al., 2005) and the PRELUDE project (EEA, 2005) does not go below a spatial resolution of 10 minutes. Such a coarse resolution is not sufficient to identify changes in landscape pattern given the importance of local conditions for landscape changes. Although macro-economic demands and demographic pressure are important drivers of land use change at the national scale, most decisions concerning land use conversions are made by individual land owners and managers that also respond to the local environmental and socio-economic context. The large diversity in environment across Europe makes it important to account for the different conditions these actors are facing. A high spatial resolution enables to account for the typical multi-scale influence of the driving factors that steer the competition of the different land use sectors for land resources. Different landscapes are expected to react differently to these internal and external pressures. Current studies at the European extent do not provide sufficient detail to assess the landscape level impacts. There is no agreement on the most appropriate scale in terms of resolution and extent for studying landscape change (Gardner, 1998; Wu and Qi, 2000). Ideally multi-scale approaches would be conducted. This paper will present a method that uses a much more detailed spatial resolution than previous studies at the European extent and will enable to identify a number of critical changes in landscape structure and composition. Also for sustainability impact assessment of land use effects on issues like biodiversity and carbon stock changes a high spatial resolution is needed since most impacts are dependent on the characteristics of the location. An additional argument for a spatial approach in the analysis of land use change is related to the policies that need to be evaluated using the modelling framework. Many policies aimed at rural areas are focusing on specific areas that do not always correspond to national or administrative areas. Examples of such policies include the Less Favoured Areas Compensation scheme targeted at rural landscapes and livelihoods and the Natura2000 network which is targeted at biodiversity conservation.

This chapter describes the approach for simulating land use changes as used in the SENSOR project. The methodological discussion is illustrated with an example for one scenario to show how the results can be used to support policy discussion.

# 2 Methodology

## 2.1 Overall approach

Land use change is the result of human-environment interactions at different scales: from trade of commodities at the global level to the effect of soil conditions on land management of a specific farm field. Within SENSOR land use change is analysed by several research groups that each focus on a particular set of processes, scale and sector. In addition to these sectoral analyses, multi-sectoral models are used that deal with the competition and interactions between these processes over different scales and the different economic sectors directly related to land use. Such multi-sectoral analysis is needed because different sectors often compete for the same land resources. It is often the interaction between the changes in the different land use sectors that determine the change in landscape and the potential multi-functionality of the land use system. When such a multi-sectoral analysis would be conducted at the national level only it would still be hard to identify whether or not sectoral changes result in a further integration or segregation of land use functions: multi-functionality is determined by the interaction of the different sectors over a range of different scales from the regional demand to local potentials.

The major economic processes leading to land use change at the scale of individual countries are captured by the NEMESIS model (Brecard et al. 2006), while a more detailed allocation (disaggregation) of land use change within the countries is done by the Dyna-CLUE simulation model.
Figure 1 illustrates the approach that is followed. Besides the multi-sectoral analysis of both NEMESIS and Dyna-CLUE a range of sectoral analyses and models are used. Partly, these sectoral models are integrated in the NEMESIS model to determine the land requirements by the different sectors. In other cases the sectoral models are used to derive simplified relations between drivers and changes within the sector that can be used within the multi-sectoral models. The model coupling is described in more detail by Jansson et al. (2008).

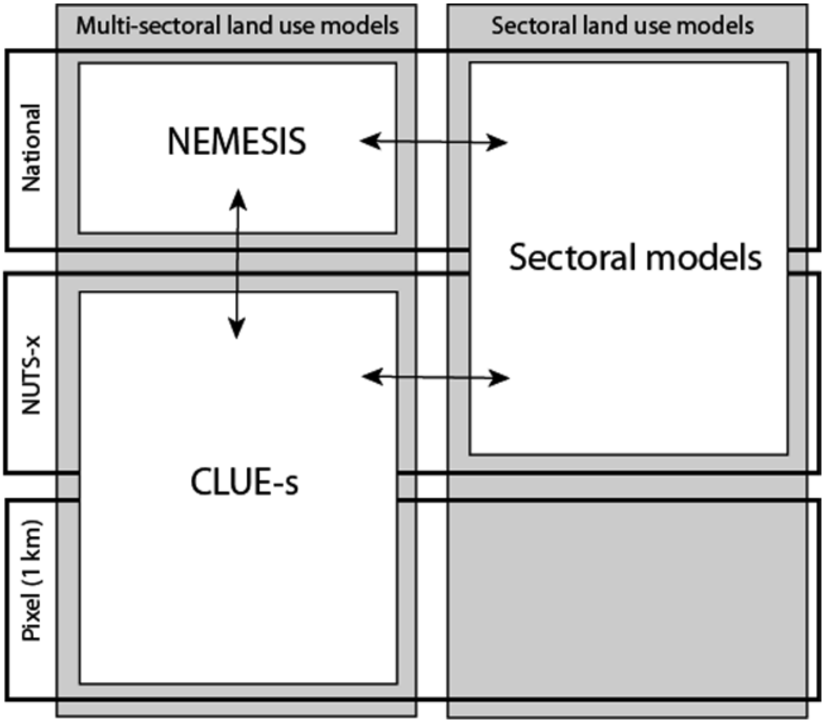


**Fig. 1.** Overview of modelling approach at different spatial scales

## 2.2 Dyna-CLUE modelling

The Dyna-CLUE (Conversion of Land Use and its Effects) model is a tool to simulate the spatial allocation of land use changes (Verburg et al. 2002, Verburg et al., 2006b). The model combines a number of popular, well-established approaches that have evolved in land use modelling over the past decades (Verburg et al., 2004b). In this sense the model may be classified as a spatial dynamic, hybrid land use change model that is based on pixel-level simulation. The choice of using pixels, spatial entities, instead of agents as basic units of simulation is based on the difficulty to parameterise agent-based models beyond the local level where appropriate data may be collected by interviews. For regional to continental scale applications the use of agent-based models is therefore considered difficult and mostly inappropriate (Matthews et al. 2007).

Depending on the study area and scenario conditions the user can configure the Dyna-CLUE model in different ways to address specific scenarios or policy cases.

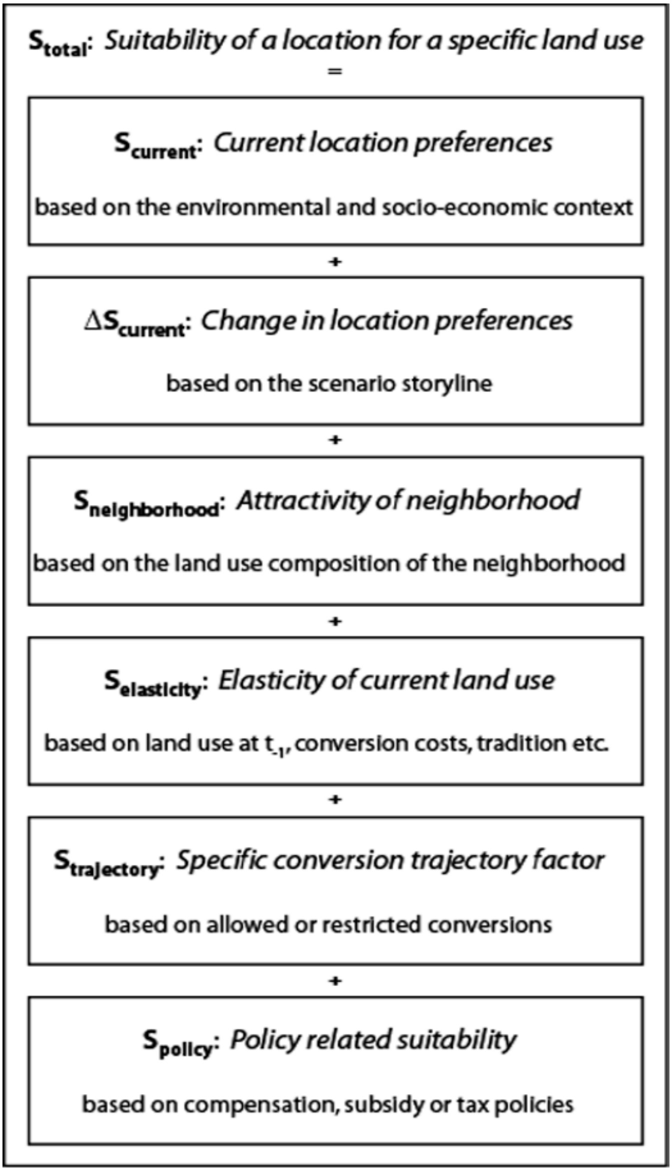


**Fig. 2.** Components used to calculate the suitability of a location for a specific land use

The model is based on the dynamic simulation of competition and interactions between land use types. The actual allocation is based on a set of constraints and preferences that reflect the characteristics of the land use type, location and the assumed processes and constraints relevant to the scenario. Given the competitive advantage of a specific land use type as determined at the national level by the economic models, each location is used for the land use type with the highest suitability at that location. The suitability is calculated as the sum of a number of values that reflect the determinants of the total suitability (Figure 2). The main determinant of the total suitability is the current location preference in response to the location characteristics such as soil, slope, climate and accessibility of markets. These preferences can be estimated based on expert knowledge or by econometric models (Verburg et al., 2004a).

While econometric models can only be based on current or historic conditions it is possible to update this location suitability by scenario specific decision rules that reflect changes in land allocation decisions, e.g. reflecting a more rational land allocation. Especially for urban land uses the neighbouring land uses may be an important determinant of the location suitability.

Agglomeration effects and economies of scale can lead to a preference for urbanization in the neighbourhood of current urban areas. This factor needs to be updated during each time step to reflect changes in neighbourhood composition during the simulations. Another component of the total suitability may be based on the current land use pattern and reflect the relative elasticity of land use changes. Most land conversions involve high costs and land owners are often reluctant to change land use as result of tradition or tenure conditions. Depending on the land use type considered it is possible to increase the suitability for a certain land use type if that location is already occupied by that specific land use type.

The ‘specific conversion trajectory factor’ reflects modifications in suitability as result of physical conditions or policy regulations, e.g., it is very unlikely that current urban areas are converted to agriculture. Therefore, the suitability of urban area for agricultural use is drastically decreased by this factor. On the contrary, policy may subsidize certain conversions at specific locations. It is possible to include this type of policies by increasing the suitability at that location for the targeted land use type. The total suitability of a location for a specific land use type is the weighted sum of these different factors. Differences between scenarios are obtained by differences in demand and the values that make up the total suitability of the different locations.

The approach considers 17 different land use types which include: rainfed arable agriculture, irrigated agriculture, arable land devoted to the cultivation of biofuel crops, grassland, abandoned agricultural land, built-up area, forest, semi-natural vegetation, and a number of land use types that are assumed to show little dynamics in time (including beaches, glaciers and bare rock). Land that is identified by the model as abandoned farmland can develop spontaneously into semi-natural area and, ultimately, into forest. The time needed for spontaneous regeneration of natural vegetation is location dependent and based on the growing conditions, grazing pressure and human intervention.

## 3 Results

Figure 3 to 6 show, aggregated at the level of NUTSx regions (a combination of NUTS2 and NUTS3 regions of comparable size) the resulting changes for the most important land use types in the Baseline scenario (Kuhlman, 2008) of SENSOR. The differences in land use change between the different member states are a direct result of the simulations performed with the NEMESIS model (Brecard et al., 2006). It should be noted that the NEMESIS results are currently based on a preliminary model run while improvements of the model are underway. Overall quantities of change are a reflection of the macro-scale results of the NEMESIS model.

In contradiction to other scenario studies of future land use in Europe including EURURALIS (Meijl et al., 2006; Verburg et al., 2006b), ATEAM (Rounsevell et al., 2006b) and SCENAR2020 (Nowicki et al., 2007) the sensor baseline scenario predicts increases in agricultural area in several European countries, especially for arable agriculture. These increases result from continued market support together with a growing worldwide demand for agricultural products. In combination with a continuing urban growth this leads for a number of countries to a loss of semi-natural vegetation and forest. From the results it is clear that large differences between the different NUTS regions within the member states exist. Due to differences in environmental and socio-economic conditions different regions will respond differently to the national level changes in demands for land. It is clear that agricultural abandonment will, in most countries, take place in those regions that have the least favourable conditions for agricultural production although this is counteracted to some extent by the less favoured areas compensation scheme of the European Unions that compensates farmers in designated regions for the less favourable production conditions. Other regions with decreasing agricultural area coincide with regions that face high urbanization. Urban land demand often out-competes agricultural land, even in areas that are relatively suitable for agricultural use. Most expansion of agricultural area takes place in regions that have favourable conditions for agriculture with, in the current situation, unprotected areas of natural vegetation.

These different trends together with strong differences between countries lead to a very diverse pattern of agricultural land use change across Europe. The pattern of urbanization is mostly based on current concentrations of urban areas. The changes in natural vegetation are reflecting the consequences of both agricultural change and urbanization. Natural areas protected by the Natura2000 networks of protected areas are unchanged or see an increase in natural vegetation as result of land abandonment. Regions with large increases in either urban or agricultural area inevitably will face more pressure on natural areas.

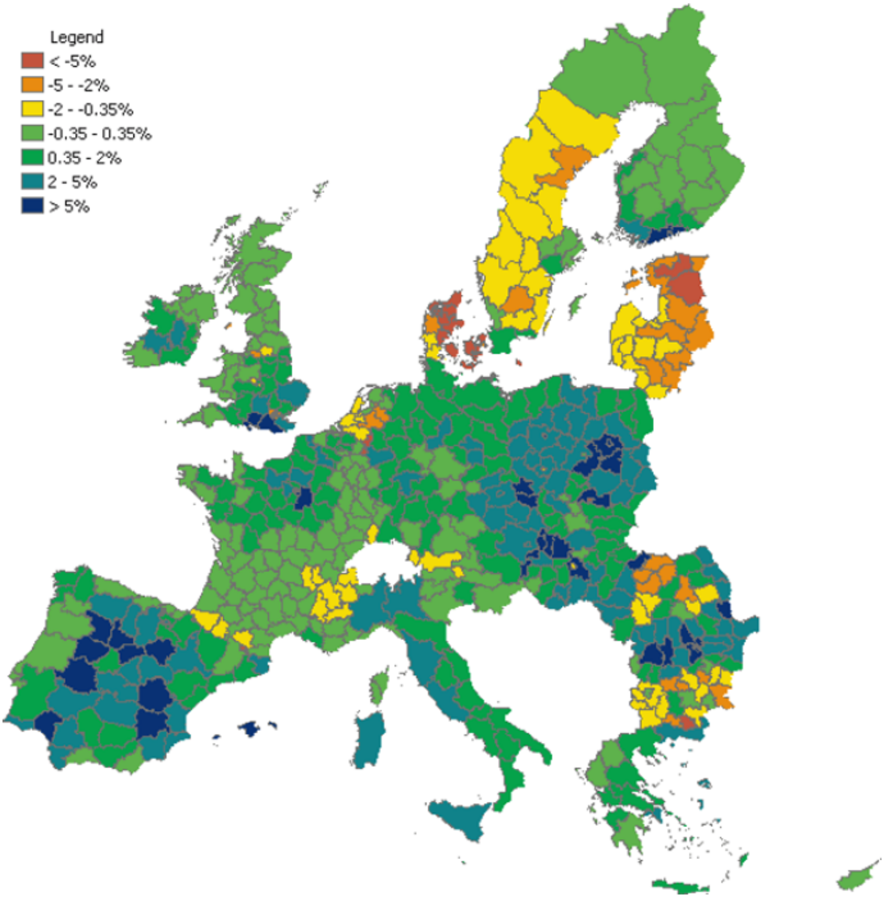


**Fig. 3** Change in agricultural area between 2000 and 2025 (relative to the total NUTS area)

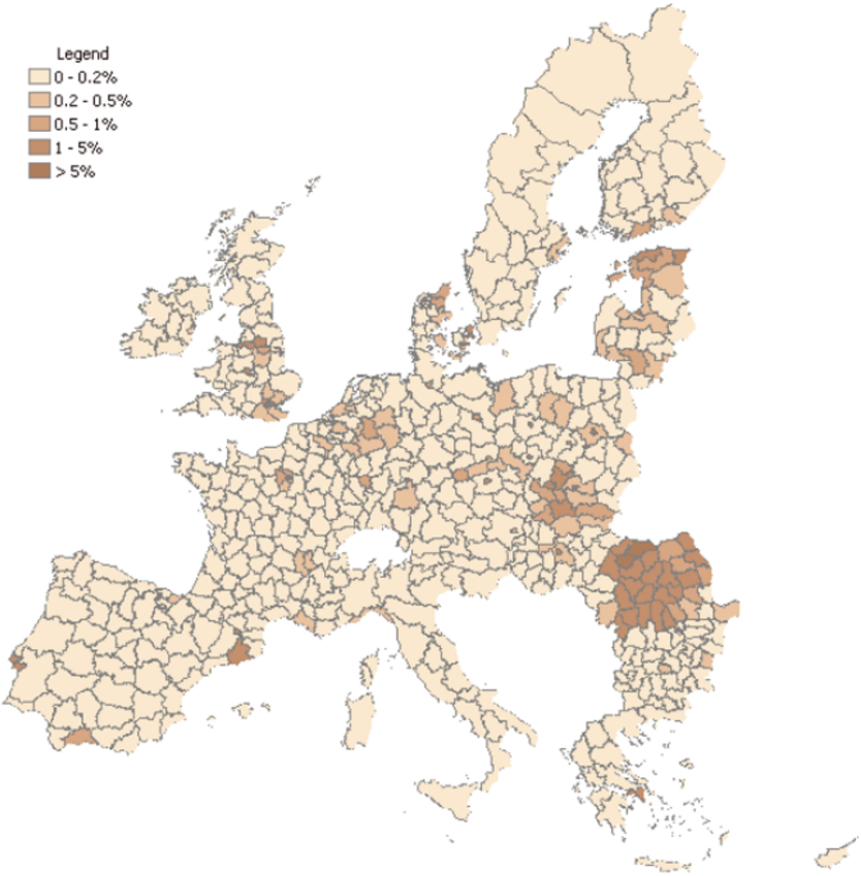


**Fig. 4.** Change in built-up area between 2000-2025 (relative to the total NUTS area)

The results presented in Figure 3 to 5 are aggregated at the NUTSx level to provide an overview of the most important land use conversions across Europe. However, these results give little insight in the changes in landscape within these NUTSx regions. Even within NUTSx regions land use change often has a high level of spatial variation leading to differential impacts.

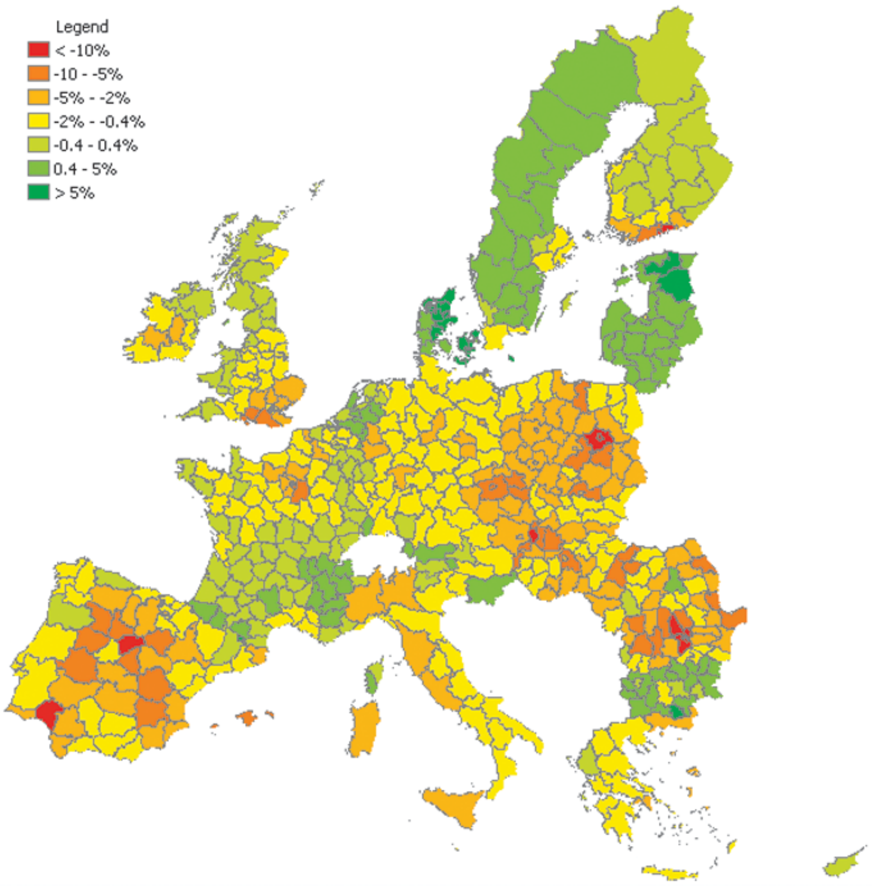


**Fig. 5.** Change in natural areas (relative to the total NUTS area)

The results at a spatial resolution of 1 $km^2$ do allow an analysis of landscape changes for specific regions showing the different trajectories of land use change. Based on these changes in landscape it is also possible to assess the possible consequences of these changes on biodiversity, carbon sequestration, soil erosion and other, landscape related, indicators.

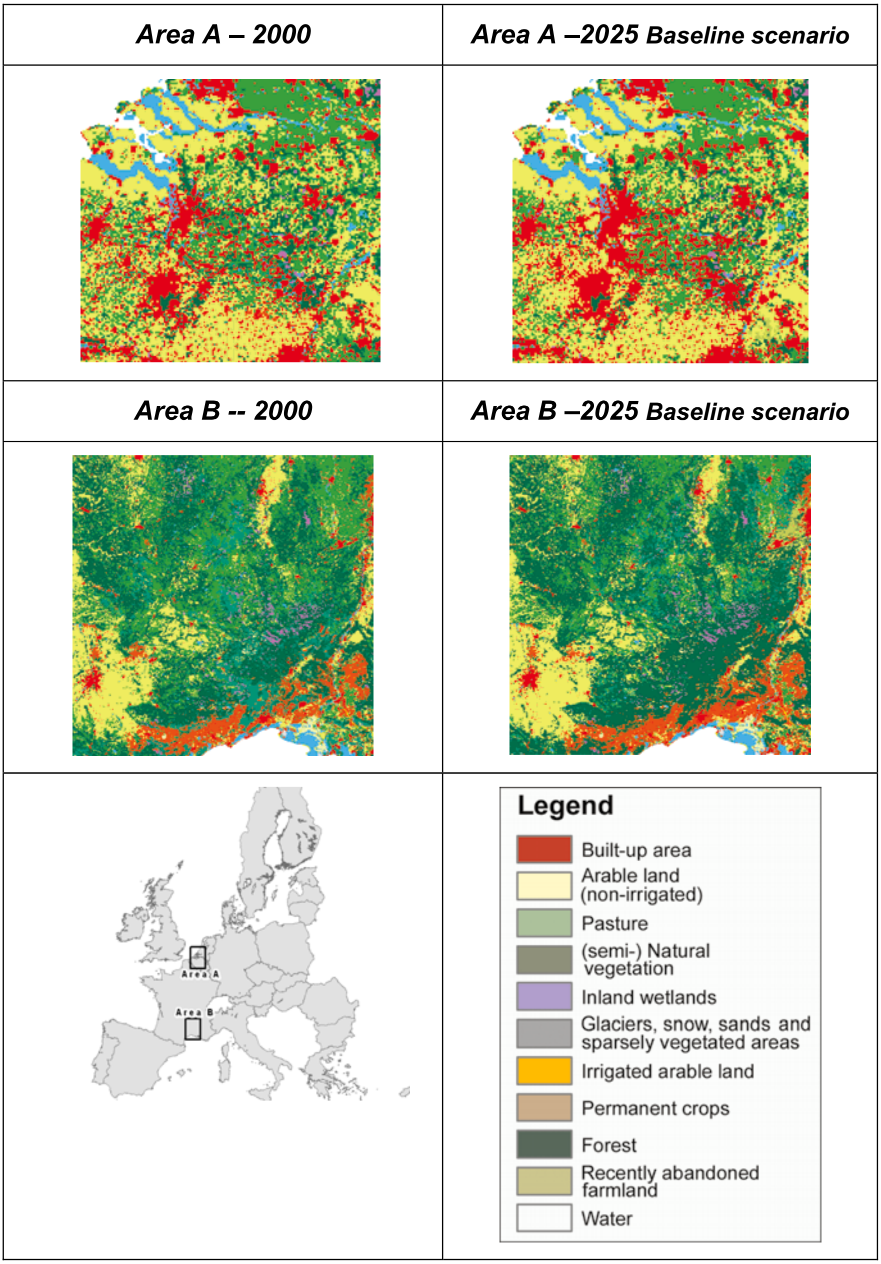


**Fig. 6.** Two examples of regional impacts of land use change

Figure 6 gives examples of these landscape level changes for two areas with diverging developments. Area A represents the urbanizing region of the southern Netherlands and Belgium. Apart from a continuing urbanization with large spatial impacts agriculture also remains an important land use during the period of simulation. This comes at the cost of a large number of small patches of forest and semi-natural vegetation. The protected forest areas are however well-preserved. A contrasting development is found in southern France. Large parts of this area are marginal for agricultural use and demographic projections indicate a further depopulation of the area. Agricultural areas will therefore be abandoned and gradually convert into semi-natural vegetation and forest. The southern part of the area is dominated by permanent crops, mostly vineyards. These are expected to expand during the simulation period.

## 4 Discussion

The integrated, multi-sectoral, approach presented in this chapter is essential when analysing possible policy effects on the (multi-)functionality of landscapes. Although the regional or national aggregate change may be an important measure of the consequences of certain developments, it does not provide insight in the impact of the changes for the landscape itself. The functionality of a landscape is typically a result of the regional context and local potentials. This study has indicated that changes in land use are not evenly spread over a country or region but show distinct spatial patterns. Although the aggregate decrease in agriculture for a country may be very modest, some regions within the country may still face a considerable decrease of agricultural area with large impacts on landscape, livelihood and environment.

These locations may face large changes in current functionality, but may as well provide potential for the development of alternative or new functions. The visualisation of land use change patterns is also helpful in discussing the options of alternative policies or design targeted measures aimed at critical regions or processes of change. At the same time the analysis at the European extent helps to frame local case studies (Eetvelde and Antrop, 2004; MacDonald et al., 2000) in a wider context and may help to indicate for which areas similar developments can be expected. Visualisation of the main conversions in maps may be supplemented by other visualisation techniques to support the discussions on future land use and landscape change (Appleton et al., 2002; Dockerty et al., 2006).

In this chapter we have only presented the results of a baseline scenario of changes in Europe. It is, however, not difficult to imagine that also for other scenarios or for specific policies similar simulations can be conducted comparable to previous scenario studies (Busch, 2006, Verburg et al., 2006a). In case of other scenarios it is most likely that the demands for urban and agricultural area are different at the national level, which may affect areas not affected in the scenario presented in this chapter. For the evaluation of specific policies it is possible to regionally adapt the constraints and options of the land use allocation procedure: e.g., nature protection policies may be implemented by excluding the protected areas from potential conversions. This way it is possible to evaluate both the European-wide pattern of land use change as well as the specific trajectories of landscape change within the different European regions. This type of information can be useful to assess impacts on land use change while, at the same time, it visualises the potential changes in landscape for use in policy discussions. The high level of integration between sectors and between economic and environmental drivers of land use change may be an incentive for a balanced evaluation of land use related policies that determine the future of the (multi-) functionality of European landscapes. At the same time it should be noted that, in spite of the high spatial resolution, it is not possible to use the results for the analysis and planning of individual regions and landscapes. Although general trajectories of land use and landscape change can be identified more detailed, region specific studies are needed that include region specific data, location factors and policies. Rather, the analysis at the European level can assist in pin-pointing regions of prime interest for such more detailed explorations or help to identify regions with similar land use trajectories and impacts.

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