Proposed land use scenario analysis, model input parameters and allocation rules

BARBOSA, Ana, et al.

Abstract

This report presents the analyses of the land use scenarios, a review of the combined method used to quantify the enviroGRIDS land use demand and the disaggregation of the global scenarios at a regional scale.

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Abstract:

The enviroGRIDS scenarios comprise a number of plausible alternatives (storylines) based on a coherent set of assumptions, key relationships and driving forces, to create a set of quantitative, internally consistent and spatially explicit scenarios of future demography, climate and land use covering the entire Black Sea Catchment (BSC).

This report presents the analyses of the land use scenarios, a review of the combined method used to quantify the enviroGRIDS land use demand and the disaggregation of the global scenarios at a regional scale. Global land use demand was obtained from IMAGE 2.2 and disaggregated at regional (NUTS2) level. Afterwards a cellular automaton based land use model was applied to allocate the land use demands at local level. Land use allocation rules were assigned based on the scenario storylines and local decision rules. As a result, four alternative land use scenarios were derived: BS HOT, BS ALONE, BS COOP and BS COOL. The designation of allocation rules introduces local decisions based not only on the scenario storylines and expert knowledge but also on historical land use patterns. The method used can fill the gap between the global and regional scales and consequently translate land use patterns at various spatial levels.
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1. Introduction

1.1 Background

The enviroGRIDS project explores the use of web-based services to share and process large amounts of key environmental information within the Black Sea Catchment (BSC). Work Package 3 (WP3) aims to develop a number of plausible alternatives (storylines) based on a coherent set of assumptions, key relationships and driving forces, to create a set of quantitative, internally consistent and spatially explicit scenarios of future demography (3.1), climate (3.2) and land use (3.3) covering the entire BSC.

Land use modelling and prediction based on the IPCC-SRES framework have attracted considerable interest over the last decade, as clearly demonstrated by the increase in European research initiatives, including the reviewed FP7 and EEA studies, most of which aim to provide policy support. A review of modelling tools developed and/or applied in previous projects also reveals an extensive choice of available models. The latest global land-cover map products have inherent limitations in using current global land cover datasets, and it would be wise to utilise multiple datasets for comparison (enviroGRIDS_D33_Landcover).

EnviroGRIDS scenario development started with the construction of four alternative storyline scenarios based on the IPCC-SRES and related approaches. An extensive overview of the future state and trends in major driving forces was presented. Then a framework for building the actual scenarios was proposed by applying the available data, information and modelling tools. The main outcome of this work was the drafting of the first version of storylines about possible changes in the BSC (enviroGRIDS_D34_Scenarios).

The enviroGRIDS land use scenarios provide an alternative vision of what the future might be like, on a 1 km x 1 km grid in two time steps (2025 and 2050) for four different scenarios covering the BSC. The land use scenarios focus on the main land cover categories: cropland, grassland, forest and urban. Land use allocation rules and area demand for 2025 and 2050 are considered for these categories. Urban areas are also used in the demographic scenarios task (enviroGRIDS_D35_Scenarios).

1.2 Objectives of this report

The purpose of this report is to show the method used to quantify the enviroGRIDS scenarios so that they could be integrated into the land use allocation model. The aim is to analyse the land use scenario storylines, to present the methodology for quantifying land use demands and to describe the land use allocation rules. In other words, the land use scenario storylines were translated into quantitative information to create spatially explicit scenarios. The following models were used for this purpose:

- IMAGE 2.2, a global model used to quantify land use scenarios for the main regions comprising the BSC (REF EE, OECD and Former USSR),
- Land use demand, disaggregated at the regional level and entered into the Metronamica regional model,
- A cellular-automaton-based model (Metronamica land use model), which will allocate land use at landscape level (1 km by 1 km) (forthcoming deliverable).

In addition to land use quantification, the calibration and validation processes are also described. The calibration process required two land use maps: the 2001 MODIS land use map (T0) for the start of the simulation period; and the 2008 MODIS land use map (T1) for the end of the simulation period. Calibration was carried out multiple times until equilibrium was reached in the agreement between the predicted land use for 2008 and the independent data (the original 2008 MODIS land use map).
Finally, one of the four scenarios was run to check the behaviour of the model using the estimated land use demand for three BSC regions: OECD, REF EE and Former USSR.

1.3 Document structure

EnviroGRIDS scenario storylines are translated into quantitative estimates of land use demands for the BSC. First a brief overview is given of the analysis of historical land use (Chapter 2). The enviroGRIDS land use scenarios and driving forces are assessed (Chapter 3) and then the global land use demands are disaggregated at regional level, using IMAGE 2.2 land use/cover projections for the regions that make up the BSC (3.1). Finally, the land use allocation rules (3.2) are described based on the land use scenario descriptions and the historical land use analysis presented in the previous chapters.

The second part of this report concerns calibration and validation (Chapter 4). First the calibration process is described for the selected regions (4.1) and then the results are assessed (4.2). Finally, to understand the behaviour of the land use model results, land use demand in the BS HOT scenario was tested for 2025 and 2050; three sample sites are discussed in section 4.3.
2 Historical land use analysis

The historical analysis of land use changes was based on a comparison between MODIS datasets from 2001 and 2008.

The main goal of this analysis was to provide information for setting the calibration parameters. The analysis of current land use maps is important due to the fact that a clear understanding of the behaviour of land use dynamics in the BSC is needed in order to establish rules to reflect this behaviour in the future.

The first step consisted of preprocessing the land cover data for the BSC, resampling from the original resolution of 500 m x 500 m to a coarser resolution of 1 km x 1 km, and aggregating the MODIS land use classes to suit the capabilities of the Metronamica land use model (Table 1), which can only manage a limited number of classes.

<table>
<thead>
<tr>
<th>MODIS Land use classes</th>
<th>Metronamica land use classes</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Water</td>
<td>Feature</td>
</tr>
<tr>
<td>1</td>
<td>Evergreen needleleaf forest</td>
<td>Forest</td>
</tr>
<tr>
<td>2</td>
<td>Evergreen broadleaf forest</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Deciduous needleleaf forest</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Deciduous broadleaf forest</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Mixed Forests</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Closed Shrubland</td>
<td>Vacant</td>
</tr>
<tr>
<td>7</td>
<td>Open Shrubland</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Woody Savannas</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Savannas</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Grasslands</td>
<td>Function</td>
</tr>
<tr>
<td>11</td>
<td>Permanent wetlands</td>
<td>Feature</td>
</tr>
<tr>
<td>12</td>
<td>Croplands</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Urban and built-up</td>
<td>Function</td>
</tr>
<tr>
<td>14</td>
<td>Crops/natural vegetation</td>
<td>Vacant</td>
</tr>
<tr>
<td>15</td>
<td>Snow and ice</td>
<td>Feature</td>
</tr>
<tr>
<td>16</td>
<td>Barren or sparsely vegetated</td>
<td>Vacant</td>
</tr>
</tbody>
</table>

Table 1: MODIS land use classes and the new classes created to fit the Metronamica land use model

The classes were divided into three groups (categories):

1. **Vacant** classes only change as a result of other land use dynamics, such as abandoned land and natural land use types. They either are literally vacant due to the absence of other land use types or result from the disappearance of other land use types.
2. **Function** classes are land use classes that are actively modelled, like residential or commercial and, in some applications, also natural and agricultural land uses.
3. **Feature** classes are land use classes that are assumed not to change in the simulation, such as water or airports.

We present the analysis of land use classes modelled with the Metronamica Land Use model. This analysis will therefore only take into account the **vacant** (crop/natural vegetation, shrubland and barren) and **function** (forest, cropland, grassland and urban) categories (Table 1).
The exercise consists of analysing land cover flows. Land use conversions and an analysis of losses and gains from 2001 to 2008 can help explain the main relationships between two or more land cover classes.

_Total area per land use in 2001_ is the total area of the BSC occupied by each land cover class in 2001 (Figure 1). Croplands are the largest class in the BSC (1,725,915 km$^2$) followed by forest (692,493 km$^2$), natural vegetation (553,006 km$^2$) and grassland (535,494 km$^2$).

![Figure 1: Total area per land use class in 2001](image1)

_Total area per land use in 2008_ is the total area of the BSC occupied by each land cover class in 2008. Compared to land use cover in 2001, croplands were still the major land use type in the BSC in 2008 (1,734,497 km$^2$) (Figure 2). However, forest areas increased, most probably due to conversion from natural vegetation. Urban and built-up areas also increased during this period.

![Figure 2: Total area per land use class in 2008](image2)

_Share of total area per land use in 2001_ (Figure 3) shows that the main classes are croplands, covering 47.2% of the total area of the BSC, followed by forest at almost 19% and crops/natural vegetation at 15.12%. Barren or sparsely vegetated areas and permanent wetlands cover less than 1% of the total area examined.
Share of total area per land use in 2001 (Figure 3) shows that the main category is croplands, covering 47.4% of the total area. Forest comes second at almost 21.29%, followed by grassland at 14.49%. Barren or sparsely vegetated areas and permanent wetlands cover less than 1% of the total BSC area.

Share of total area per land use in 2008 (Figure 4) shows that the main category is croplands, covering 47.4% of the total area. Forest comes second at almost 21.29%, followed by grassland at 14.49%. Barren or sparsely vegetated areas and permanent wetlands cover less than 1% of the total BSC area.
Absolute change in area for vacant and function land use classes between 2001 and 2008

The contingency table shows class relations between 2001 and 2008 (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>Vacant</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td>Crops/natural vegetation</td>
<td>Shrubland</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>Grassland</td>
</tr>
<tr>
<td>Crops/natural vegetation</td>
<td>311720</td>
<td>2556</td>
</tr>
<tr>
<td>Shrubland</td>
<td>1376</td>
<td>22223</td>
</tr>
<tr>
<td>Barren or sparsely vegetated</td>
<td>64</td>
<td>2036</td>
</tr>
<tr>
<td>Forest</td>
<td>85378</td>
<td>4611</td>
</tr>
<tr>
<td>Grassland</td>
<td>23183</td>
<td>31394</td>
</tr>
<tr>
<td>Croplands</td>
<td>129911</td>
<td>12229</td>
</tr>
<tr>
<td>Urban and built-up</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Absolute change flow within land use classes

Table 2 shows the cross-tabulation of land use in 2001 (columns) against land use in 2008 (rows). Where a land use in a row meets the same land use in a column, the value in the corresponding cell is the area that did not change from 2001 to 2008. The other values represent the areas that changed from one land use class to another during the study period.

This matrix can be used to analyse the contributions to net change in each function land use: forest, grassland and cropland.

The main contribution to the increase of forest areas is from crop and natural vegetation (51045 ha), followed to a lesser extent by grassland (28006 ha), shrubland (3569 ha) and cropland areas (2108 ha), (Figure 5).

Figure 5: Net change to forest from other land use classes between 2001 and 2008

The abandonment of agriculture is clearly shown during this period with a high percentage of land use conversion to natural vegetation (19657 ha) and shrubland (5909 ha). Additionally, some grassland is
converted to cropland (14583 ha); this is related to intensification and expansion in suitable areas and disappearance in less suitable areas (Figure 6 and Figure 7).

Figure 6: Net change to cropland from other land use classes between 2001 and 2008

Forest and grassland are very competitive with each other. On one hand, forest areas tend to be converted to grassland (often with cropland as an intermediate step) and grassland to forest. On the other hand, some grassland areas are converted to cropland, in the case of regions experiencing agricultural intensification, or to shrubland, in cases of land abandonment.

Figure 7: Net change to grassland from other land use classes between 2001 and 2008

Figure 8 shows the main land use changes between 2001 and 2008. The largest positive change occurred in the forest class (over 80,000 km²). Croplands increased in area by 8,582 km². The largest negative change occurred in grassland, which lost more than 5,000 km².
The differences within the period 2001–2008 are also presented on maps of the BSC regions and adjacent areas. These regions are a combination of NUTS (Nomenclature of Territorial Units for Statistics) levels 2 and 3. Four function land use classes were analysed: forest, grassland, croplands and urban/built-up areas.

The absolute difference in square kilometres for the forest class shows that significant positive changes in the flow of forest land use occurred mostly in the northern, extreme western and south-western parts of the BSC. Negative changes occurred in smaller patches along an east-west line across the middle of the BSC (Figure 9).

In general terms, grassland flows from 2001 to 2008 show a decreasing trend in the BSC, where the most negative changes were recorded in the mid-west (Romania). To a lesser extent, some positive changes were found in the south (Turkey) and east (Russian Federation) (Figure 10).
Croplands (Figure 11) show a negative absolute difference in the extreme east (Russian Federation) and south (Turkey), as well as in the mid-west (northern Romania). A significant positive trend occurs along the western and northern Black Sea shores and in Belarus, as well as in the western part of the BSC, though to a lesser extent.

The absolute difference in the area covered by urban and built-up areas (Figure 12) is less significant than for the rest of the function classes. This can be explained by the shortness of the period analysed. Regions that recorded a negative difference are located close to the Black Sea shore in Romania, Ukraine and Turkey.
3 EnviroGRIDS land use scenarios

The scenarios proposed in enviroGRIDS consist of a number of plausible alternatives (storylines) that are based on a coherent set of assumptions of key relationships and driving forces, in order to create a set of quantitative, internally consistent and spatially explicit future climate, demography and land use scenarios covering the entire BSC.

EnviroGRIDS storylines are based on the IPCC-SRES (Nakicenovic et al., 2000). Four marker scenarios represent different global socio-economic development pathways: in the vertical axis, ‘A’ represents the more economically oriented scenarios and ‘B’ the more environmentally and equity oriented ones; in the horizontal axis ‘1’ represents the more globalized and ‘2’ the more regionalized scenarios. Additionally, development of the enviroGRIDS scenarios was partly supported by other related global scenario studies, such as World Water Vision (Cosgrove and Rijssberman, 2000), Global Scenario Group (Kemp-Benedict et al., 2002) and Four Energy Futures (Bollen et al., 2004), as well as European studies such as ATEAM (Rickebusch et al., 2011), EURuralis (Klijn et al., 2005) and Prelude (EEA, 2005).

A first draft of the enviroGRIDS scenarios was presented in the previous report (enviroGRIDS D 3.4), and consisted of an interpretation of these scenarios, including a qualitative assessment, identification of the main driving forces (Table 3) and presentation of the enviroGRIDS storylines.

A workshop on enviroGRIDS scenarios was subsequently held in Delft, the Netherlands, to discuss the draft scenarios. This workshop brought together a group of experts in demography, climate and land use. The main goal of this workshop was to debate aspects of data availability, uncertainties and underlying driving forces, and to clarify the scenario storylines. The four resulting enviroGRIDS scenarios are presented in Figure 13.
**EnviromGIDS – FP7 European project**
Building Capacity for a Black Sea Catchment Observation and Assessment System supporting Sustainable Development

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**Figure 13: EnviromGIDS scenarios – BS HOT, BS COOP, BS ALONE and BS COOL**

BS HOT corresponds to the IPCC’s A1FI scenarios (emphasis on fossil-fuels – Fossil Intensive), with high economic development and free-market policies, where environmental issues are not the main concern. BS COOP refers to the B1 climate scenarios, involving strong international cooperation in which environmental concerns are taken seriously: the Kyoto protocol target is achieved through such cooperation.

On the other side, the BS ALONE and BS COOL scenarios correspond to the A2 and B2 regional scenarios, respectively. In both scenarios local identities are preserved, with the possible break-up of the EU and the reinforcement of national military capabilities. In the BS COOL scenario, economic growth is contained by local environmental policies, with local bodies implementing strategies to promote local sustainable development. On the other hand, in the BS ALONE scenario, the regions are very competitive and environmental pressures are very high.
The proposed storylines for each land use scenario are presented below:

**BS HOT** – In this scenario the highest economic growth is assumed, with low population increase, free-market policies, very large increase in greenhouse gas emissions, and consequently global climate change. This also implies very high environmental pressures in the areas of the Black Sea Catchment, which could be partially alleviated by rapidly emerging technological developments. In general, agricultural areas will decline in the Black Sea Catchment due to strong urbanization. Abandoned land tends to turn into urban areas or natural vegetation and forest. Forest areas will increase in all countries initially, but afterwards will decrease in western countries and increase in eastern countries. Urbanization rates will increase due to population movement from rural to urban areas and consequently there will be an expansion of built-up areas. Urban areas are expected to increase in highly populated regions as a result of high rates of economic development and population growth. As a result of high population growth, high economic growth leads to a larger use of space per person and consequently growth in the industry and services sectors. Meanwhile, in sparsely populated areas, natural areas associated with agricultural abandonment are expected to increase.

**BS ALONE** – The BS ALONE scenario is characterized by lower levels of trade and regionally oriented economic growth. In the eastern countries high economic growth and population growth are expected to decrease, while in the western countries economic growth will be lower and population growth will increase. In general, this scenario shows the highest increase in agricultural areas over the whole Black Sea Catchment, due to strong regional policies and production incentives. In this scenario there is strong competition between agriculture and urban areas. Deforestation is highly apparent in this scenario, especially in Western European countries. Nature conservation continues only within existing protected areas. The increase of urban areas is mostly due to the increase in prosperity; these new urban areas will therefore include both sprawl around existing urban areas and an increase in urban areas in tourist regions.

**BS COOP** – In the BS COOP scenario economic growth will be high and population growth will be low. Some regions are expected to lose population, mainly during the first period (2000-2025), and afterwards the population will remain stable. Economic growth rates are certainly lower than in BS HOT, but with less pronounced differences between countries. Lower growth is also foreseen during the second period (2025-2050). The emphasis is on globalization of both economic and environmental concerns. In the BS COOP scenario, strong emphasis is placed on the implementation of global environmental policies in order to cut the rise in greenhouse gases and decrease the effects of climate change in the BSC. Afforestation is strongly supported and consequently agricultural areas tend to decline, mainly in less suitable areas. Abandoned lands are expected to be converted to natural protected areas. Urban areas are expected to increase; however, this increment will be very compact (no change in size) due to the strictness of spatial policies, in particular in the western counties. In the eastern countries the planning policies are less strict and the urban areas experience stronger growth; however, this growth is lower than in the BS HOT (global economic) scenario.

**BS COOL** – This combines intermediate economic growth with medium population growth. However, a small group of countries in the BSC are expected to increase. Generally this scenario displays the most heterogeneous patterns of development in the BSC countries. In this scenario no major changes in land use are expected to happen. Urbanization is very low and consequently agricultural and forest areas are not expected to change. In this scenario the most important change to emphasize is the conversion from cropland to grassland, especially in the western countries.
Table 3 summarizes the general trends for the four variants:

<table>
<thead>
<tr>
<th>Driving forces</th>
<th>BS HOT</th>
<th>BS ALONE</th>
<th>BS COOP</th>
<th>BS COOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population growth</td>
<td>low</td>
<td>very high</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>Urban population</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
</tr>
<tr>
<td>GDP growth</td>
<td>very high</td>
<td>slower</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>Forest area</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
<td>decrease</td>
</tr>
<tr>
<td>Grassland area</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
<td>decrease</td>
</tr>
<tr>
<td>Cropland area</td>
<td>increase</td>
<td>increase</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>Built-up area</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
<td>stable</td>
</tr>
<tr>
<td>Protected areas</td>
<td>stable</td>
<td>stable</td>
<td>increase</td>
<td>stable</td>
</tr>
<tr>
<td>Climate change</td>
<td>high</td>
<td>high</td>
<td>lower</td>
<td>low</td>
</tr>
</tbody>
</table>

Table 3: Summary of land use trends and driving forces in the enviroGRIDS scenarios

### 3.1 Quantification of land use scenarios

The SRES framework is somewhat limited by its geographical scale and subjectivity. For instance, it provides derived global scenarios without guidelines to their application at a regional scale. On the other hand, the narratives allow for interpretation, which is subjective and qualitative. The land use scenarios need to be interpreted at a regional scale, sector by sector. The quantification of scenarios requires appropriate tools and models of land use change (Strengers et al., 2004).

The quantification of land use scenarios is based on the framework provided by the Integrated Model to Assess the Global Environment (IMAGE, version 2.2: IMAGE team, 2001), which is an improved version of the model that was used for the implementation of IPCC-SRES (Alcamo et al., 1998).

IMAGE 2.2 is an integration of many sector-based models (enviroGRIDS_D3.4). The basic economic information is provided by WorldScan, an equilibrium economy model, and demographic information by Phoenix. The IMAGE framework links the following components (Figure 14):

- Energy-Industry System (EIS)
- Terrestrial-Environmental System (TES)
- Atmosphere-Ocean System (AOS)
The land use model simulates changes for 17 regions instead of the 13 regions proposed for the original SRES exercise and also calculates not only different sources of greenhouse gas emissions but also the resulting concentrations, climate change and interactions among individual components (IMAGE team, 2001; Strengers, 2004).

The IMAGE model provides a large amount of data covering the IPCC-SRES scenarios from 1970 to 2100.

The land use model used in IMAGE 2.2 is a rule-based cellular automaton model combining physical and human factors. The output provided is a spatially explicit description of global land use and land cover dynamics at 0.50 x 0.50 degree resolution for 17 regions of the world. The land use model applies as input the land use cover from the previous time step, the demand for food, feed, biofuel crops and timber products, and potential vegetation (Alcamo et al., 1998; IMAGE team, 2001).

The model results have been published on CD-ROM (IMAGE team, 2001) and are also available online through the Netherlands Environmental Assessment Agency\(^1\). The model structure, input data and results are presented in a visualisation tool, User Support System (USS), which provides a comprehensive view of the scenario data of IMAGE runs.

The inherent limitation of global models is mainly the low quality of spatial resolution related to their global scale, which strongly constrains effective detection of the diversity in regional conditions of land use change. In spite of their coarse resolution, however, global models have been used in a variety of studies to

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\(^1\) Netherlands Environmental Assessment Agency ftp site (USS IMAGE 2.2 download)

quantify the different storylines, and consequently they play an important role in the assessment of large areas. EUruralis (Klijn et al., 2005) is a good example of how to fill the gap between these highly aggregated global models and local studies.

Our interest in IMAGE 2.2 comes from the land cover demands required by the spatially explicit Land Cover Model (LCM). In this study, we use the demand provided by the IMAGE 2.2 model of the IPCC-SRES scenarios to estimate the land use changes in the BSC. Land use changes in the BSC are disaggregated to regional level and are used as input to the regional/local land allocation model (Metronamica). This land use model requires the forest, cropland, grassland and urban areas for each of the 214 regions in the BSC.

The enviroGRIDS land use change scenarios give projections of land use on 1 km x 1 km grids in two time steps (2025–2050) for four scenarios, covering the whole BSC. The land use scenarios were developed for cropland, grassland, forest and urban for the BSC countries. The land use data was derived from the MODIS land cover datasets for 2001 and 2008.

The disaggregation method applied consists of estimating the land use demand for each of three regions (IMAGE 2.2 regions: OECD, REF EE and Former USSR) and disaggregating it at NUTS2 level, on the simple assumption that all NUTS2 regions have the same growth rate as the larger, more inclusive unit. Based on this relationship, land use can be disaggregated to the regional level and used as a demand for the land use demand module in the Metronamica model.

### 3.1.1 Estimation of land use scenario parameters

The IMAGE 2.2 model distinguished 19 land cover types at grid cell level (0.5 x 0.5 degree grid), including cropland, forest and grassland, for 17 regions covering the entire world. The enviroGRIDS area comprises three of these regions:

- OECD (Organisation for Economic Cooperation and Development) Europe region: Austria, Germany, Italy, Switzerland, Turkey;
- REF Eastern Europe (countries undergoing economic reform): Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Montenegro, Romania, Serbia, Slovakia, Slovenia;
- Former USSR: Belarus, Georgia, Moldova, Russia, Ukraine.

According to IMAGE 2.2, the behaviour and extent of the three key land cover classes are region-specific and are very much influenced by regional or global policies (IMAGE team, 2001; Strengers, 2004):

- Cropland corresponds to agricultural land and extensive grassland. The agriculture area represents the area allocated for food and biofuel crops.
- Grassland includes pasture and fodder crops.
- Forest areas represent the extent of different forest types: mature forest, regrowth forest after the abandonment of agricultural areas and regrowth forest after timber extraction. In the IMAGE model, forest areas are derived indirectly, which means from the actual distribution of natural vegetation based on the potential vegetation and the actual land use. Consequently, a fraction of each vegetation class was assumed to consist of forest (e.g. 10% of tundra is forest, and 30% of grassland and steppe is forest).

The following tables (Table 4 to 7) show the estimated scenario parameters for the three regions included in the BSC.
In the BS HOT scenario, forest is expected to increase in the Former USSR during the whole period while it is expected to increase only during the first time step (up to 2025) in the REF EE countries, followed by a decrease during the second (2025–2050). This increase in forest is due to agricultural abandonment and lower demand for biofuel crops, so that these areas turn into other natural land cover classes such as forest.

In the OECD countries, forest areas will decrease due to rapid economic and population growth in China and India, resulting in an increased demand for food. Europe thus becomes a large exporter region, due to the high quality of its agricultural land.

Agricultural areas are expected to decrease in the Former USSR during the entire period and in REF EE countries during the first step (up to 2025). Abandoned land is partially taken over by urban land (for residential, industrial and recreational purposes), essentially in highly populated regions. In sparsely populated regions, agricultural areas are expected to be converted to natural vegetation. In regions with low levels of agriculture, agricultural land tends to disappear and to be converted to other land use/cover classes, such as forest.

Grassland in the Former USSR and REF EE countries is not expected to change, whereas it is likely to increase in the OECD countries, possibly in connection with the increase in food demand. The changes in land use demand for the OECD, REF EE and Former USSR regions under BS HOT are shown in Table 4.

<table>
<thead>
<tr>
<th>BS HOT (A1FI)</th>
<th>Forest</th>
<th>Agriculture</th>
<th>Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2025</td>
<td>2050</td>
<td>2025</td>
</tr>
<tr>
<td><strong>Growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OECD</td>
<td>-0.08</td>
<td>-0.26</td>
<td>0.13</td>
</tr>
<tr>
<td>Eastern Countries</td>
<td>0.29</td>
<td>-0.10</td>
<td>-0.20</td>
</tr>
<tr>
<td>Former USSR</td>
<td>0.01</td>
<td>0.04</td>
<td>-0.05</td>
</tr>
<tr>
<td><strong>Index</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OECD</td>
<td>0.92</td>
<td>0.74</td>
<td>1.13</td>
</tr>
<tr>
<td>Eastern Countries</td>
<td>1.29</td>
<td>0.90</td>
<td>0.95</td>
</tr>
<tr>
<td>Former USSR</td>
<td>1.01</td>
<td>1.04</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Table 4: BS HOT scenario: relative changes in the demand for agriculture, grassland and forest based on IPCC-SRES – IMAGE 2.2 (source: IMAGE team, 2001)

In the BS ALONE scenario, deforestation occurs throughout the century globally. In the BSC regions, it is most prominent in the OECD countries. In the REF EE countries, however, forest areas are expected to increase slightly during the first step (up to 2025) and remain the same in area in the second (2025–2050). Forest areas in the Former USSR will remain almost the same during both steps (Table 5).

In this scenario there is strong competition between agriculture and urban areas, with conversion of small natural vegetation patches to urban or agriculture. Agricultural areas will increase in the OECD, especially for biomass crops to satisfy the energy demand. In the Former USSR and the Eastern countries, agricultural areas are expected to decrease during the first step and increase during the second.

In BS ALONE, grassland areas are expected to follow the same trend as in BS HOT: Former USSR and REF EE countries retain the same area, and the OECD region increases its grassland area possibly in connection with rising food demand.
EnviroGRIDS – FP7 European project
Building Capacity for a Black Sea Catchment Observation and Assessment System supporting Sustainable Development

Afforestation is strongly supported during the century in BS COOP. However, in the BSC regions, forest areas tend to slightly decrease over the entire period in the OECD countries and during the second step (2025–2050) in the REF EE countries. In the Former USSR, the area of forest will increase, through the expansion of both existing forest areas and smaller patches (Table 6).

In general, agricultural areas will decrease across the whole BSC, especially in regions with a low comparative advantage, and small patches of agriculture will disappear. In general, abandoned agricultural areas will be converted to natural protected areas.

An exception is expected for the second time step in the OECD countries, where agricultural areas are expected to increase slightly, particularly in highly agricultural regions. This fact could be related to Europe becoming a large exporter of agricultural products to overpopulated countries. In this scenario, a shift is expected from cropland and shrubland to grassland and from grassland to cropland. Grassland areas are expected to increase a little or remain the same over the whole BSC. An exception is expected for the OECD during the second step (2025–2050) due to the conversion of grassland to cropland areas.

The BS COOL scenario combines intermediate economic growth with medium population density increase globally. In the BSC, however, only in the recently developed group of countries are population numbers
expected to increase. In general, this scenario reveals the most heterogeneous patterns of development in the BSC countries.

In the BS COOL scenario, land use changes are expected to be modest due to low urbanization over the BSC. The distribution of agriculture is expected to change only slightly. Although cropland areas tend to shrink, crop productivity is expected to increase. The most important change to highlight in the BS COOL scenario is the conversion from cropland to grassland, especially in the OECD countries (Table 7).

<table>
<thead>
<tr>
<th>Growth</th>
<th>Forest</th>
<th>Agriculture</th>
<th>Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Eastern Countries</td>
<td>0.19</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Former USSR</td>
<td>0.01</td>
<td>-0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>OECD</td>
<td>0.99</td>
<td>1.01</td>
<td>1.02</td>
</tr>
<tr>
<td>Eastern Countries</td>
<td>1.19</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Former USSR</td>
<td>1.01</td>
<td>0.92</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 7: BS COOL scenario: relative changes in the demand for agriculture, grassland and forest based on IPCC-SRES – IMAGE 2.2 (source: IMAGE team, 2001)
3.1.1.1 Agriculture, grassland and forest demand for the BSC regions

Once the enviroGRIDS scenario storylines have been decided and the growth rates estimated for each IMAGE region (OECD, REF EE and Former USSR), the next step is to translate the IMAGE scenarios into quantitative values for each of the 214 regions in the BSC, to be integrated into the Metronamica land use model. The relative growth of agriculture, extensive grassland and forest in the IMAGE 2.2 land use changes were disaggregated to cropland, grassland and forest (enviroGRIDS land use classes). For example, in the BS HOT scenarios, the NUTS2 regions included in the REF EE region will have a 29% increase in forest demand by 2025. Thus the region of Vest in Romania, which had a forest demand of 12,780 km$^2$ in 2008, will have an increment of 3,708 cells by 2025. The total forest demand in 2025 in Vest will be 16,488 cells.

The enviroGRIDS demands for the whole BSC for each land use in the BS HOT, BS ALONE, BS COOP and BS COOL scenarios are compared in Figure 15.

In all the scenarios, agricultural areas are expected to decrease during the first time step and increase slightly in the second. Despite this increase, the total areas will stay below the total area in 2008. Only the BS ALONE regional economic scenario shows an increase in crop areas compared to the baseline year, which is due to policies to maintain agricultural production, while the globally oriented scenarios show strong differences. In BS COOP spatial policies reinforce natural protected areas and consequently agricultural areas are abandoned and converted to natural areas. In the BS HOT scenario, the total agricultural area declines after 2025, reaching lower values than in 2008. In this scenario energy supply is strongly based on fossil fuels, leading to a smaller increase in demand for biofuel crops.

In the previous three scenarios (BS ALONE, BS COOP and BS HOT), grassland (pastures and fodder) areas will increase in the first step and decline during the second. Only in the regional scenario BS ALONE is total grassland area in 2050 expected to be higher than in 2008. In the BS COOL scenario, grassland areas will remain the
same. Cropland is expected to be converted to grassland and grassland to other land use types. In the global scenarios (BS COOP and BS HOT), grassland areas increase during the first step and afterwards decline to lower values than observed in 2008.

The changes in land use have important consequences in forest areas. Across all the scenarios, forest areas tend to increase slightly until 2025 and then decline until 2050. The BS ALONE scenario shows relatively minor changes in forest areas. In the BS HOT scenario forest area declines much more than in the other scenarios, due to major landscape changes influenced by urban sprawl and agricultural abandonment.

Figure 16 shows the relative percentages of the main land use types in the BSC in 2050. In summary:

- The largest area of agriculture and grassland in the BSC is observed in the economic/regional scenario: BS ALONE.
- The smallest area of agriculture in the BSC is observed in the environmental/global scenario: BS COOP.
- The largest area of forest in the BSC is observed in the environmental/regional scenario: BS COOL.
- The smallest area of forest in the BSC is observed in the economic/global scenario: BS HOT.

Figure 16: Major land use types in 2050 for all enviroGRIDS scenarios compared with the base year 2008.
3.2 Spatial allocation rules

Spatial allocation rules are specified for each scenario and are used to allocate land use demand at local level in the BSC. The attribution of spatial allocation rules is based on the following conditions (Verburg et al., 2006):

- Land use patterns nearly always exhibit spatial autocorrelation. This spatial correlation can be explained by (a) the clustered distribution of landscape types under environmental conditions that are important determinants of land use patterns; and (b) the spatial interaction between land use types (new urban areas arise close to existing urban areas).

- Spatial autocorrelation in land use patterns is scale dependent – residential areas are generally clustered because of positive spatial autocorrelation. However, if there are negative spatial externalities resulting from development, such as traffic, new parcels are repelled from existing residential parcels.

- Spatial interactions can also act over larger distances – for example, a change in land use upstream might influence land use changes downstream.

The most popular method to implement neighbourhood interactions in land use models is the Cellular Automaton (CA) model. The CA model can simulate both simple and complex land use patterns and behaviours. They are defined (Clarke and Gaydos, 1998) by:

- Assuming a single action space (usually a grid);
- Assuming a set of initial conditions;
- Assuming a set of behaviour rules (transition rules between cell states based on neighbourhood states).

In land use, CA models the transition of a cell from one land use to another depending on the state of the neighbourhood cells. Calibration is very complex due to the many interacting coefficients. Different processes (rules) can originate identical patterns. The diverse possibilities in setting the transition rules and the neighbourhood lead to large uncertainties and error propagation (Yeh and Li, 2006, in Verburg et al., 2006).

Recently several authors have been studying sets of transition rules that match reality better. A good initial set of transition rules is very important. The transition rules in CA models are based on analyses of past trends in land uses, analyses of storylines and expert knowledge.

In Metronamica, the demand calculated for each region is allocated on the land use map by means of a cellular automaton rule-based allocation model, on a 1 km x 1 km grid. The area modelled is represented by a mosaic of 4,164,536 cells of 1 ha each, representing the predominant land use pattern of the BSC. Land use changes will occur according to spatial allocation rules which will define attraction/repulsion, local constraints and suitability. The dynamic interaction of each land use cell and its neighbourhood is simulated through cellular automaton rules.

In this chapter, land use allocation rules are described for each scenario and are based on an analysis of historical changes, expert knowledge and analyses of the main land use conversions (between forest, agriculture, grassland and urban). These rules determine the degree to which land use is attracted to, or repelled by, other main land uses (functions) present in its surroundings. If the attractiveness is strong enough, the function will try to occupy the location; if not, it will look for more attractive places (RIKS, 2005).
In general terms, urban areas tend to expand mainly into agricultural areas. Agricultural areas tend to convert to urban, natural and forest areas. Agriculture has the highest transition rate to forest (temperate mixed forest) in the BS HOT scenario, and it also has a high conversion rate to grassland in all four scenarios. The highest rate of conversion from grassland to agriculture occurs in BS COOP. Conversion of shrubland to grassland occurs in BS HOT and BS COOP. Conversion from forest to agriculture occurs in all scenarios, with the highest rate occurring in BS HOT and BS COOP. BS ALONE has the largest agricultural areas.

Land use allocation rules based on historical land use transitions and enviroGRIDS scenarios are summarized below. Table 8 describes the trend for each land use (in italics) and gives the allocation rules based on the scenario storyline.

### BS HOT

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agriculture</strong></td>
<td>Agricultural areas will decrease and be abandoned due to high urban sprawl. Easy conversion to urban. Easy conversion to natural areas, forest, and grassland.</td>
</tr>
<tr>
<td><strong>Grassland</strong></td>
<td>Total grassland areas will decrease. Easy conversion from shrubland to grassland.</td>
</tr>
<tr>
<td><strong>Forest</strong></td>
<td>Forest areas will increase due to the abandonment of agricultural areas. Easy conversion of agriculture to forest, as well as forest to agriculture. The forest area becomes more compact.</td>
</tr>
<tr>
<td><strong>Urban</strong></td>
<td>Increase of urban areas and demand in densely populated regions. Strong attraction of urban in agricultural areas around existing settlements.</td>
</tr>
<tr>
<td><strong>Protected areas</strong></td>
<td>Protected areas will be restricted to existing areas.</td>
</tr>
</tbody>
</table>

### BS ALONE

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agriculture</strong></td>
<td>Agricultural areas will increase. Strong competition with urban areas. Inertia for cropland, with strong neighbour interactions fading gradually. Easy conversion of natural areas to cropland. Easy conversion of cropland to grassland.</td>
</tr>
<tr>
<td><strong>Forest</strong></td>
<td>Slight competition between agriculture and forest. Easy conversion of forest to cropland.</td>
</tr>
<tr>
<td><strong>Urban</strong></td>
<td>Urban areas and urban demand will increase. Dispersed urban sprawl – new settlements are expected in tourist areas. Inertia in existing urban areas with strong neighbour interactions fading gradually – some expansion of existing small towns. Easy conversion of natural areas to urban.</td>
</tr>
</tbody>
</table>
**Protected areas**  
*Protected areas will be restricted to existing areas*

---

**BS COOP**

**Agriculture**  
*Agriculture increases in highly agricultural regions.*

- Inertia in existing agricultural areas with strong neighbour interactions fading gradually.
- Abandonment of agriculture in less agricultural regions – small patches disappear.
- Easy conversion of agriculture to natural areas.
- Easy conversion of grassland to cropland, as well as cropland to grassland.
- Easy conversion of shrubland to grassland.

**Forest**  
*Forest areas increase.*

- Inertia in existing forest areas with strong neighbour interactions fading gradually – existing forest areas and smaller patches expand.
- Easy conversion of forest to agriculture.

**Urban**  
*Urban areas increase (EE).*

- *Urban areas increase in density but not in area (WE) – compact growth as urban areas stick to their present locations.*

**Protected areas**  
*Natural areas will convert to new protected areas.*

---

**BS COOL**

**Agriculture**  
*Agricultural areas decrease slightly.*

- Inertia for agricultural areas as they stick to their present locations.
- Easy conversion of cropland to grassland.

**Forest**  
*Forest areas increase.*

- Inertia and attraction for forest diminishing with distance.

**Urban**  
*Urban areas increase slowly.*

- Inertia for urban areas as they stick to their present locations – small changes (WE).

**Protected areas**  
*Protected areas will be restricted to existing areas.*

---

Table 8: Land use allocation rules for the BS HOT, BS ALONE, BS COOP and BS COOL scenarios
4 Calibration and validation

Calibration and validation of spatial dynamic land use models are essential to obtain an accurate model. There is currently a vigorous debate on theoretical and practical aspects, in which scientists are investing considerable research efforts. In most cases, these processes are based on a comparison of model results for a historical period with the actual changes in land use as they have occurred. Calibration mostly focuses on researching how to adjust parameters to improve the model results until they match the reference data as closely as possible, whereas validation is the application of different methodologies to evaluate the data obtained. During the calibration process, the model runs different kinds of dynamic equations, which are applied to and solved for each modelled land use cell.

Metronamica is a modelling framework that supports the development and application of spatially dynamic land use models enabling the exploration of spatial development in cities, regions or countries caused by autonomous developments, external factors and policy measures, using structured what-if analysis (RIKS, 2005). Through the dynamic generation of year-by-year land use maps and different kinds of indicators, including spatially explicit economic, ecological and socio-psychological factors represented at a high-resolution scale, the model shows trends, impacts and inputs from stakeholders.

Metronamica operates with three methods for a semi-automatic calibration (one for regional mode, one for local mode and one for linked global-regional-local model) (Figure 17). The global model (a single administrative or physical entity) consists simply of timelines that are the driving force of the regional mode. Historical data can be used for the global model, requiring no calibration. The regional model (n administrative or physical entities within the global level) works directly above the local model providing the land use demand per region. The local model (N cell units within each regional entity) is the constrained cellular automaton model; this is the most calculation-intensive level and requires the most parameters. A more detailed description of calibration is found in the next section.

4.1 Calibration

The Metronamica software is divided into three levels: Global, Regional and Local. The global level is represented by different factors entered into the model, such as overall population, activity per economic sector, and expansion of a particular land use.
At the regional level, a dynamic spatial interaction-based model (White, 1977, 1978) explains the fact that national growth will not be spread evenly over the modelled area. Instead, regional inequalities will influence the location and relocation of new residential areas and new economic activities, and thus drive regional development.

At the local level, the regional demands are allocated by means of a cellular automaton rule-based allocation model that can be applied to a grid with a resolution varying between ¼ ha and 4 ha (Couclelis, 1985; White and Engelen 1993, 1997; Engelen et al., 1995, in RIKS, 2008). For calibration at local level there are five different factors involved in the land use allocation phase: neighbour effect, accessibility, suitability, zoning and a stochastic component. These factors are included in the same allocation algorithm, so they cannot be calibrated separately (Figure 18). Any change applied to one of these factors will influence the final product for the whole calibration. In practical terms, all the factors listed above are multiplied to find the total potential \( TP \) for a function land use in a certain location, so the formula can be summarized as:

\[
TP = (1 + (-\log[(1 - \text{random}])))^\kappa \times N \times \lfloor if N \geq 0; A \times S \times Z; 2 - A \times S \times Z \rfloor
\]

Where \( \text{random} \): Stochastic factor; \( \kappa \): Random coefficient; \( N \): Neighbourhood effect; \( A \): Accessibility; \( S \): Suitability; and \( Z \): Zoning

The total potential formula shows the influence of the different components on the final allocation potential for each cell. For example, if one component yields a value of 0 on a specific location, as in the case of zoning \((Z)\), it cannot be compensated by the other components. This is one of the main reasons why zoning effects are added only in the final stage of the calibration.

![Figure 18: Factors involved in the calibration procedure at local level](image)

The calibration phase needed to adjust the parameters and to run the model for such a large area is very time consuming. For this reason, calibration was set up on a sample of 23 regions. These regions were selected to best represent the landscape of the entire BSC.
The 23 regions were selected by establishing certain conditions. The first group of regions was selected for the existence of the majority of transitions between both function and vacant land use classes from 2001 to 2008. Therefore regions lacking one or more land use types (function and vacant) were also included. Finally regions with different types of urban areas (dense and scattered) were also included. Table 9 shows the list of regions selected to calibrate the Metronamica application:

<table>
<thead>
<tr>
<th>Region Number</th>
<th>Country</th>
<th>Region Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Austria</td>
<td>Tirol</td>
</tr>
<tr>
<td>59</td>
<td>Croatia</td>
<td>Jadranska Hrvatska</td>
</tr>
<tr>
<td>49</td>
<td>Georgia</td>
<td>Kakheti</td>
</tr>
<tr>
<td>52</td>
<td>Georgia</td>
<td>Racha-Lechkhumi and Kvemo Svaneti</td>
</tr>
<tr>
<td>53</td>
<td>Georgia</td>
<td>Samegreb-Zemo Svaneti</td>
</tr>
<tr>
<td>39</td>
<td>Germany</td>
<td>Oberbayern</td>
</tr>
<tr>
<td>63</td>
<td>Hungary</td>
<td>Dél-Dunántúl</td>
</tr>
<tr>
<td>67</td>
<td>Italy</td>
<td>Lombardia</td>
</tr>
<tr>
<td>69</td>
<td>Italy</td>
<td>Autonomous Province of Trento</td>
</tr>
<tr>
<td>107</td>
<td>Romania</td>
<td>Sud-Est</td>
</tr>
<tr>
<td>146</td>
<td>Russia</td>
<td>Volgograd Region</td>
</tr>
<tr>
<td>159</td>
<td>Russia</td>
<td>Republic of North Ossetia - Alania</td>
</tr>
<tr>
<td>166</td>
<td>Slovenia</td>
<td>Western Slovenia</td>
</tr>
<tr>
<td>28</td>
<td>Switzerland</td>
<td>Ostschweiz</td>
</tr>
<tr>
<td>171</td>
<td>Turkey</td>
<td>Istanbul</td>
</tr>
<tr>
<td>175</td>
<td>Turkey</td>
<td>Bursa</td>
</tr>
<tr>
<td>176</td>
<td>Turkey</td>
<td>Kocaeli</td>
</tr>
<tr>
<td>181</td>
<td>Turkey</td>
<td>Kayseri</td>
</tr>
<tr>
<td>187</td>
<td>Turkey</td>
<td>Agri</td>
</tr>
<tr>
<td>188</td>
<td>Ukraine</td>
<td>Autonomous Republic of Crimea</td>
</tr>
<tr>
<td>202</td>
<td>Ukraine</td>
<td>Odessa Oblast</td>
</tr>
<tr>
<td>208</td>
<td>Ukraine</td>
<td>Kherson Oblast</td>
</tr>
<tr>
<td>214</td>
<td>Ukraine</td>
<td>Sevastopol</td>
</tr>
</tbody>
</table>

Table 9: Regions selected for calibration

Figure 19 shows the flowchart of the calibration procedure (RIKS, 2005). The usual calibration steps are illustrated, starting from the default parameters upon setup. Each step will be explained more in detail in the next section. Calibration includes an iteration process, the procedure being repeated until a satisfactory result is reached.
EnviroGRIDS – FP7 European project
Building Capacity for a Black Sea Catchment Observation and Assessment System supporting Sustainable Development

Figure 19: Flowchart showing the calibration procedure step by step
4.1.1 Neighbourhood rules

The calibration procedure starts with the adjustment of neighbourhood rules, which lie at the heart of cellular automaton land use models. These rules define the relationship between land use classes as a function of distance. This relationship can be divided into three elements:

- **Inertia** represents the strength of influence of a land use class on itself, at distance 0.
- **Conversion** represents the capacity to change from one land use class to another, at distance 0.
- **Attraction and repulsion** represent the influence of a land use class on itself or on another class at distance 1 or more.

Land use dynamics are influenced by different rules, which are based on local decisions and land use patterns. Each land use class will have different rules from other land use classes. Those neighbourhood rules that most closely mimic real land use transition behaviour provide the best results. Rules may need to be adjusted several times to achieve a good fit, which can be a slow process. The following graphs (Figure 20) show examples of possible settings for the three types of neighbourhood rule: inertia or attraction, conversion only and attraction only.

![Graphs showing examples of inertia, conversion and attraction settings for neighbourhood rules](image)

**Figure 20**: Example of inertia, conversion and attraction settings for neighbourhood rules
Table 10 gives an overview of different cases that represent possible settings obtained through the assignment of simple values. Each setting reflects a particular interaction between land use classes and distance.

<table>
<thead>
<tr>
<th>Distance functions</th>
<th>Meaning of the distance function in socio-economic and geographical terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect at distance = 0 of the function on itself.</td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Inertia" /></td>
<td><strong>Inertia</strong>: expressing the strength with which the existing land use will stick to its present location.</td>
</tr>
<tr>
<td>Effect at distance = 0 of any other function on the function.</td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Ease of re-conversion" /></td>
<td><strong>Ease of re-conversion</strong>: the ease with which a new land use will take over from the existing land use (blue: easy re-conversion, such as infill; red: difficult re-conversion, for example re-conversion of brownfields).</td>
</tr>
<tr>
<td>Effects at distance &gt; 0</td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="No interaction" /></td>
<td><strong>No interaction.</strong></td>
</tr>
<tr>
<td><img src="image" alt="Attraction" /></td>
<td><strong>Attraction</strong>: positive agglomeration benefits diminishing with distance.</td>
</tr>
<tr>
<td><img src="image" alt="Repulsion" /></td>
<td><strong>Repulsion</strong>: negative agglomeration benefits diminishing with distance.</td>
</tr>
<tr>
<td><img src="image" alt="Change in type of interaction" /></td>
<td><strong>Change in type of interaction</strong>: from attraction to repulsion and/or vice versa.</td>
</tr>
<tr>
<td><img src="image" alt="Strong interaction with far neighbours" /></td>
<td><strong>Strong interaction with far neighbours, abruptly falling.</strong></td>
</tr>
<tr>
<td><img src="image" alt="Gradual distance decay" /></td>
<td><strong>Gradual distance decay.</strong></td>
</tr>
<tr>
<td><img src="image" alt="Strong interaction with immediate neighbours" /></td>
<td><strong>Strong interaction with immediate neighbours, gradually falling.</strong></td>
</tr>
<tr>
<td><img src="image" alt="Sphere of influence" /></td>
<td><strong>Sphere of influence</strong>: <em>short tail</em>: the interaction is limited to short distances; <em>long tail</em>: the interaction effect works over longer distances.</td>
</tr>
</tbody>
</table>

Table 10: Generic distance functions available to build the distance rules of the cellular automaton land use model (source: RIKS, 2005)
4.1.2 Random parameter

The random parameter interprets land use change in a cell that does not follow the behaviour defined by ordinary rules, representing the uncertainty of cell allocation. In the model, the setting value can vary from 0.1 to 1, where an increase in the factor leads to an increase in the scatter of the cell distribution in the final land use map. This value has to be adjusted until the results approximate the reference data.

4.1.3 Suitability maps

A suitability map is assigned for each land use type, representing the probability of change in the future, and can be created through logistic regression or multi-criteria methods (Pontius and Schneider, 2001). The suitability maps created for Metronamica were based on contingency tables drawn up to evaluate the relationship between land use change and driving factors. Each land use class was crossed with a physical factor, to underline the frequency of distribution per land use classes. The results were studied and compared through graphics and matrices. At the end of this procedure, the significant factors that were taken into account to generate suitability maps were the following: elevation, slope, soil quality, mean annual temperature and annual precipitation. ESRI ArcGIS and Overlay tools (RIKS, 2006) were used to prepare these maps. The resulting overlay map represents the suitability of a given cell to maintain a particular land use (Uljee et al., 2006). Land use suitability is represented on a scale ranging between 1 and 10. Figure 21 shows the suitability map for forest, where 1 represents a low probability that forest will occur and 10 a high probability that forest will occur.

Figure 21: Example of a suitability map for forest

The annual mean temperature and annual precipitation applied in the generation of the suitability maps are climate surfaces with a spatial resolution of 1 km, from WorldClim. The WorldClim climate surfaces were generated by interpolation using the thin-plate smoothing spline algorithm (WorldClim; Hijmans et al., 2005) from the average monthly climate data from weather stations for the period 1950–2000 (Figure 22).
The suitability maps were updated after the calibration process with the mean annual temperature and annual precipitation projections for 2050. Initially the climate projections were obtained from the WorldClim datasets for the available IPCC climate scenarios (A1, A2 and B2), downscaled from the third-generation coupled global climate model (Ramirez and Jarvis, 2010). Subsequently the climate surfaces were replaced with more accurate climate surfaces derived from the downscaling of the PRUDENCE regional climate model to the BSC weather stations (enviroGRIDS_D3.2).

### 4.1.4 Accessibility effects

Accessibility is an expression of the ease with which an activity can fulfil its need for transportation and mobility in a particular cell based on the transport system (RIKS, 2008). These effects are based on rail networks, rail stations and road networks with major and secondary roads extracted from the ESRI base maps database (Global Road Data, 2006; ESRI Data & Maps, 2006). First, these datasets are each edited into single shape files with an additional field [acctype] to establish a priority order among the data. When entered in the model, a weight is assigned according to the function land use class. Therefore the model recognizes the areas which are affected in a positive or negative way by the infrastructure network. The influence of the infrastructure network will be greater on urban spread and the emergence of new allocation sites. Urban areas are more likely to grow the closer they are to a road or rail network. In contrast, the presence of an infrastructure network has little influence on the other land use classes. In the case of cropland, roads are a minimum requirement, while no particular weight will be assigned for grassland and forest as no direct relation is recognized. Figure 23 shows the accessibility map for urban areas. Green represents high accessibility for urban areas, and red indicates low accessibility for urban areas.
4.1.5 Zoning maps

Zoning maps are inserted only at the end of the procedure. They may be regarded as institutional suitability maps because they represent political limits, such as urban plans or protected areas. A zoning map is needed for each function land use modelled. Policymakers and planners use this function to constrain or stimulate particular changes or permanence of land use. The data used to create the zoning maps for this project were obtained from the World Database on Protected Areas, and from two UNEP/GRID-Europe products, one for the Fire Events map, based on the World Fire Atlas (WFA, ESA-ESRIN) dataset, and the other for the Food Risk map, modelled using global data for the Global Assessment Report on Disaster Risk Reduction (2009).

The World Database on Protected Areas offers data that cover the BSC area at two levels of precision; thus two protected area maps were created. These maps were reclassified for use in Metronamica by decreasing the number of the original IUCN classes without changing the hierarchy structure. Before introducing the zoning maps, it is important to define a hierarchy of importance between the different layers, so that in cases of overlap higher layers take priority over lower ones. Each land use class has a zoning map that can receive one of five different settings for change potential, from ‘strictly’ or ‘weakly restricted’, to limit change, to ‘actively stimulated’ or ‘allowed’, to favour change, and ‘unspecified’ when there is no marked influence. The main restrictive effect produced by protected area maps is on the urban class: where an area has been officially designated a National Park or Natural Reserve it will clearly not be possible to expand an urban area or plan a new one in the future. The same effect is expected for cropland on protected areas; thus the model recognizes areas set as ‘strictly’ or ‘weakly restricted’, and forces changes onto other classes (Figure 24).

The fire events map represents areas affected by a high frequency of fire events. This allows for the generation of restrictions to changes in urban, forest and cropland land use classes; however, this dataset may also be used to identify positive interactions that favour the presence of grassland. The relationship between the various land use classes and fire events can change depending on the region, for political and physical reasons, so it is difficult to generate general rules for the entire BSC.
The flood risk map shows the areas where the impact of potential flooding is strongest. This is helpful to exclude those particular areas from the allocation of new activities connected with urban areas or cropland. For forest and grassland, there is no significant relationship with this zoning plan.

Figure 24: Example of a zoning map for urban land use.

4.2 Validation of calibration results

The calibration process requires two land use maps: the 2001 land use map (T0) for the start of the simulation period, and the 2008 land use map (T1) for the end of the simulation period. The model is parameterized taking the 2001 land use map as a reference map, so that the simulated land use map at the end of the calibration period can then be compared with the actual land use map in 2008 (T1) (Figure 25) (RIKS, 2005; van Vliet et al., 2011). During the calibration process the model parameters (neighbourhood rules) are adjusted to improve the model goodness of fit.

Figure 25: Calibration, validation and extrapolation process for the BSC (adapted from RIKS, 2005)

The validation process demonstrates that the range of accuracy of the model results is satisfactory (Rykiel, 1996, in Lambin, 1999). In this case, validation consists of measuring the agreement between the predicted
land use for 2008 and independent data (the reference 2008 land use map). If there is a good fit between the model prediction and the validation dataset, then the model is considered capable of making accurate extrapolations to other spatial and temporal extents (Figure 25).

The validation process requires two land use maps. Usually, a third map (T3) is used in the calibration process; however, in this case the third map is not available. The T1 map used during the calibration period will be used for the validation period. Therefore, the simulated land use map (2008) is compared with reference maps for the same period (T1). The higher the agreement between the maps, the better the accuracy, and consequently extrapolation to other spatial and temporal extents will be improved.

In this chapter we assess the calibration results and ensure that the model is good enough to extrapolate to other spatial and temporal extents.

There are numerous methods to compare patterns in maps. The first analysis consists of visually assessing the structure of the land use patterns. This process is based on expert knowledge acquired during the calibration period. Then techniques based on a pixel-by-pixel comparison – Kappa Statistics, Fuzzy Kappa and a neutral reference model – are used to analyse the local goodness of fit.

### 4.2.1 Kappa statistics

After a visual interpretation and a general assessment, the next step is to analyse the degree of fit of the simulation at local level, cell by cell. The Map Comparison Toolkit – MCK (RIKS, 2010) was used to this end. The MCK provides the Kappa, Klocation, Khisto and Fuzzy Kappa statistics, among others, to analyse the observed values (simulated 2008) and the expected values (actual 2008).

The 2001 land use map was used as the base year and the 2008 map was used as a target map for the validation period. The land use classes used were exactly the same as those used during the calibration period.

For validation at local level the measures used to assess goodness of fit were Percentage Correct Metric Kappa, Klocation, Khisto, Fuzzy Kappa and Random Constraint Match.

The first analysis used the Percentage Correct Metric, which represents the number of hits relative to the total number of cells. The cells that were predicted to transition by the model are compared to the cells that actually changed during the same period. Figure 26 shows a map of cells that are equal and unequal in the simulated and actual maps. Red represents the cells that do not match; green corresponds to the cells that are correctly located by the model. The percentage correct metric derived from this map is around 80%.
The percentage correct metric is very complicated to interpret, however, because a large number of cells may be classified correctly due to chance. The Kappa statistic can be used to represent the proportion of agreement after chance agreement has been removed. $Kappa = 1$ means there is perfect agreement between the two maps. If $Kappa = 0$ the observed proportion correct is less than the expected proportion due to chance (Sousa et al., 2002). Kappa and its components can be computed from the contingency table.

However, Kappa is not able to specify the location accurately. The location error is calculated by $K_{location}$, which compares the actual success rate to the expected success rate relative to the maximum success rate, provided that the total number of cells in each category does not change. $K_{location} = 1$ means that the simulation specifies location correctly. If $K_{location} = 0$, the simulation has assigned location randomly.

$K_{histo}$ is another statistic derived from Kappa that can be used to analyse the comparison of the quantitative model. It corresponds to the greatest similarity that can be found based on the total number of cells occupied by each category (Sousa et al., 2002).

The Kappa value obtained from the comparison between the actual 2008 map and the simulated 2008 map was around 0.72, which can be considered a substantial agreement between the two maps. The $K_{location}$ calculated was around 0.73, which means that the simulation’s ability to specify location is good. The $K_{histo}$ result shows that 99% of cells were allocated during the simulation (Table 11).
The urban and built-up areas and water classes show the highest agreement between the simulated and real land use maps. The results obtained were 0.96, and 0.88, respectively, which means there is almost perfect agreement between the maps according to their Kappa value. Urban areas and water are relatively stable with few transitions and this facilitates the allocation rules attributed to these classes.

Forest, cropland, grassland and snow classes show good agreement between the two maps. The Kappa value obtained (between 0.80 and 0.60) indicates an acceptable level of agreement between the calibration results and reality for these classes. In this group grassland is the class with the lowest Kappa value (0.63); this fact may be associated with the global map classification. In fact, grassland located at high altitudes is probably related more to annual variations in precipitation than to actual land cover changes (figure 16 in enviroGRIDS D3.3).

Crops/natural vegetation and shrubland show moderate agreement between the real land use map and the simulated map. The Kappa values obtained were 0.48 and 0.58, respectively. These classes are much more unstable, typically changing mainly to forest and croplands. It is hard to assign allocation rules to these classes, as they tend to fluctuate and change annually.

Barren or sparsely vegetated areas and permanent wetlands are the classes that are most poorly represented in the BSC. The very low Kappa obtained shows that there is only fair agreement between reality and the simulated map. These classes are very unstable, as they are constantly changing. On the other hand, both classes are affected by the quality of classification of the real maps in 2001 and 2008. In fact, wetlands and sparsely vegetated areas are underestimated on the MODIS land cover maps, as demonstrated in the previous report (enviroGRIDS D3.3).

Fuzzy Kappa is similar to Kappa in form and interpretation, but it takes neighbourhoods into account. In the Fuzzy Kappa method the expected percentage of agreement between two maps is corrected for the fraction of agreement statistically expected from randomly relocating all cells in both maps (Visser, 2004). The assessment results are spatially allocated, representing the similarities and dissimilarities on a gradual scale, where 1 means total similarity and 0 means total dissimilarity. Intermediate values (e.g. 0.5) mean some similarity between the two maps (Figure 27).

The map shows that tolerance for small spatial differences does lead to a higher similarity of the maps. In other words, when a simulated geographical entity is near to the expected one the Fuzzy Kappa will be higher.

### Table 11: Kappa per category for actual and simulated 2008 land use maps

<table>
<thead>
<tr>
<th></th>
<th>Crops/natural vegetation</th>
<th>Shrubland</th>
<th>Barren or sparsely vegetated</th>
<th>Forest</th>
<th>Grassland</th>
<th>Croplands</th>
<th>Urban and built-up</th>
<th>Permanent wetlands</th>
<th>Snow and ice</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa</td>
<td>0.48372</td>
<td>0.58713</td>
<td>0.21095</td>
<td>0.8052</td>
<td>0.69641</td>
<td>0.75880</td>
<td>0.9604</td>
<td>0.20471</td>
<td>0.6671</td>
<td>0.8838</td>
</tr>
<tr>
<td>Kloc</td>
<td>0.48562</td>
<td>0.61693</td>
<td>0.39793</td>
<td>0.8052</td>
<td>0.69644</td>
<td>0.76141</td>
<td>0.9993</td>
<td>0.43448</td>
<td>0.8261</td>
<td>0.8931</td>
</tr>
<tr>
<td>Khisto</td>
<td>0.99609</td>
<td>0.95170</td>
<td>0.53012</td>
<td>100.00</td>
<td>0.99996</td>
<td>0.99657</td>
<td>0.9610</td>
<td>0.47116</td>
<td>0.8075</td>
<td>0.9895</td>
</tr>
</tbody>
</table>
**Simulated 2008**

**Actual map 2008**

**Figure 27: Fuzzy Kappa obtained for actual and simulated 2008 land use maps**

*Kappa Simulation* is the coefficient of agreement between simulated land-use transitions and actual land-use transitions. *KS* = 1 means perfect agreement. If the score is below 0 the class transitions are less accurate than can be expected by chance given a random allocation of class transitions. Typically, land use changes are not random; consequently the value of *KS* will usually be above 0, and any score below 0 can be understood to mean that the model does not explain any land use changes (van Vliet, 2011). In this case the *KS* obtained was around 0.31, meaning that the calibration was good.

### 4.2.2 Neutral reference model for land use changes

Random constraint match (RCM) is a neutral model used in the evaluation of simulation results (Hagen-Zanker and Lajoie, 2008). This model creates several land use maps as reference maps with the correct distribution of land use class sizes, allocated randomly over the original land use map with minimal adjustments to this original land use map. Afterwards, the reference maps are compared with simulated land use for the interpretation of the results (Figure 28).

The model calculates the number of cells for each land use class that are under- or over-estimated on the initial maps compared with the final map. Where a class is over-estimated, the model will randomly select...
the surplus number of cells of that class on the initial map. Then the under-estimated classes are distributed randomly over the selected cells on the initial map (RIKS, 2008).

Afterwards the 2008 reference land use map was compared with the RCM map. The Kappa statistic obtained from this comparison was around 0.67 (table in Figure 28), which is lower than for the comparison between the actual 2008 land use map and the simulated 2008 land use map ($Kappa = 0.72$). This result means that the model was able to perform well at a cell level and consequently the calibration was successful. The category $Khisto$ value should be 1, because the procedure for generating the RCM map allocates the correct number of cells to each land use class. $Klocation$ is always equal to $Kappa$ because the
spatial distribution of cells in the RCM is always the same. For individual land use classes, the lowest \textit{Kappa} was obtained for barren or sparsely vegetated areas (0.11) and the highest for urban and built-up areas (0.99).

### 4.3 Scenarios (test run)

In order to preview the behaviour of the Metronamica Land Use Model results, land use demand for the BS HOT scenario was tested for 2025 and 2050.

Land use scenario development is based on a combined method which includes not only analysis of historical land use and the use of appropriate tools to estimate land use demand, but also expert knowledge to adjust the resulting land use patterns.

The regional model was parameterized by means of land use demand calculated for each region from the IMAGE 2.2 land use/cover demands. Allocation rules were not taken into account for this exercise, and therefore the allocation rules used for the calibration exercise were retained.

The results show that the model was able to allocate the same number of land use demands parameterized for the regional model. However, in a few regions the number of land use cells allocated was different from the land use demand provided in the regional model. This situation occurred because of conflicts between the different demands for each land use class being allocated.

The land use model allocates first the feature classes (fixed classes) and secondly the function classes (modelled classes), based on land use demand, neighbourhood rules, random parameter, zoning maps, suitability maps and accessibility. Finally the model allocates the vacant classes based on the suitability maps wherever there are free cells that have not been occupied by function or feature classes. The results obtained show that there is not enough space left to allocate the entire cell demand for all function classes with higher demands.

Figure 29, 30 and 31 present three examples: Dél-Dunántúl (Hungary) is part of the REF EE region, Lombardia (Italy) is part of the OECD region, and Volgograd (Russia) is part of the Former USSR region.

In Dél-Dunántúl, the main land use changes occur in the forest and cropland classes. The land use map for 2025 shows that agricultural areas are disappearing. The abandoned land is converted to crops/natural vegetation and to new forest areas. In 2050 the situation is reversed: cropland areas recover and forest areas are converted mainly to cropland, as well as to crops and natural vegetation (Figure 29).

In Lombardia, forest areas decrease over the period while cropland areas increase. This increase in crop production is for export to other continents. Grassland areas decrease. On the 2025 land use map, shrubland converts to crops and natural vegetation, but in 2050 it converts to cropland. On the other hand, cropland areas also take over forest land (Error! Not a valid bookmark self-reference.).

In Volgograd, land use changes are very small. Land use demand changes are lower than in the other regions mentioned; this means that in the BS HOT scenario the Former USSR will not suffer significant land use changes. The main land use change occurs in grassland, which is converted to cropland. On the other hand, shrubland areas are converted to grassland (Figure 31).
Figure 29: BS HOT spatially explicit scenario for 2025 and 2050 – Dél-Dunántúl, Hungary
OECD Region: Lombardia, Italy

Forest BS HOT scenario

Grassland BS HOT scenario

Cropland BS HOT scenario

Urban/Built-up BS HOT scenario

Land use 2008

BS HOT Land use 2025

BS HOT Land use 2050

Figure 30: BS HOT spatially explicit scenario for 2025 and 2050 – Lombardia, Italy
Figure 31: BS HOT spatially explicit scenario for 2025 and 2050 – Volgograd, Russia
5 Discussion

The scenarios proposed by enviroGRIDS consist of a number of plausible alternatives (storylines) based on a coherent set of assumptions. They represent spatially explicit scenarios of future climate, demography and land use in the BSC. The results from the land use scenarios raise general policy questions based on the IPCC-SRES storylines and related approaches, such as World Water Vision (Cosgrove and Rijsberman, 2000), Global Scenario Group (Kemp-Benedict et al., 2002) and Four Energy Futures (Bollen et al., 2004), as well as European studies such as ATEAM (Rickebusch et al., 2011), EUruralis (Klijn et al., 2005) and Prelude (EEA, 2005).

Four markers were developed representing different global socio-economic development pathways. The BS HOT and BS COOP scenarios refer to globally oriented scenarios. BS HOT represents high economic development and free market policies where environmental issues are not the main concern. BS COOP involves strong international cooperation and environmental concerns are taken seriously: the Kyoto protocol targets are achieved through such cooperation. In contrast, the BS ALONE and BS COOL scenarios correspond to regionally oriented scenarios. In both scenarios local identities are preserved and the possible break-up of the EU is accepted; however, in the BS COOL scenario economic growth is contained by local environmental policies and local entities implement strategies to promote local sustainable development, whereas in the BS ALONE scenario the regions are very competitive and environmental pressures are high.

The IPCC-SRES (Nakicenovic et al., 2000) framework is well accepted by the policy and scientific communities and covers a wide range of the main driving forces of future emissions, from demographic factors to technology and economic development. European and global scenarios follow the IPCC-SRES reference scenario.

The Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project scenarios interpret the SRES reference scenario for Europe, developing a set of land use and nitrogen deposition scenarios that are linked to the climate and socio-economics derived from the storylines. The land use scenario was constructed for the high-priority (A1) and medium-priority (A2) scenarios based on an interpretation of the four SRES reference scenarios. The interpretation included definition of the range of driving forces for each land use type in Europe. The ATEAM project aimed to assess the vulnerability of human sectors relying on ecosystem services with respect to global change. The assessment process was developed in permanent collaboration with stakeholders. The general objective of this dialogue was to facilitate a more appropriate assessment of vulnerability, and produce results that would inform decision making by stakeholders. The stakeholders participated in a number of activities, including interviews and questionnaires to identify their scientific information needs, as well as workshops that were organized for communication purposes and to trigger discussions between stakeholders (Schröter et al., 2004).

EUruralis also takes as a starting point the IPCC-SRES and other related projects, such as ATEAM. Under this approach four scenarios were built: A1 – Global economy; B1 – Global co-operation; A2 – Continental Markets and B2 – Regional Communities. The vertical axis represented global as opposed to more regional approaches and the horizontal axis represented an open market compared with a higher level of intervention and regulation by governments (Klijn et al., 2005).

In case of PRELIDE, an EEA project, specific parameters were quantified based on the IPCC-SRES parameters or on ATEAM scenario studies. However, when stakeholder descriptions did not fit the IPCC-SRES scenarios very well, the parameters were adjusted based on expert judgment and observed data on past and recent trends (Volkery, 2008). From the beginning of PRELIDE (EEA, 2005), scenarios were
developed by a diverse panel of 30 specialists, including researchers, interest group representatives and members of the general public. Different interests and perspectives were included. The stakeholder groups, modellers and experts engaged in a creative, interactive process to provide the input for scenario development. This process involved the development of qualitative storylines based on exhaustive discussions about key uncertainties and underlying driving forces.

In the SENSOR project, three baseline scenarios were developed: a reference scenario, which is largely business-as-usual but with adjustments based on expert judgment, and two contrasting scenarios for high- and low-growth options (Helming et al., 2008). A Framework for Participatory Impact Assessment (FoPIA) was developed in this project (Morris et al., 2008), involving national, regional and local stakeholders in the assessment of land use policy impacts. This system was structured around the same logical framework that defines the design parameters of the model-based SIAT – the EEA DPSIR framework. FoPIA supported discussions among stakeholders, key players and decision makers, providing a forum for the exchange of knowledge with the aim of gaining an understanding of the potential application and consequences of proposed policy changes. This framework involved five stakeholder workshops focusing on different tasks, as follows: first workshop – refining the scenarios; second workshop – analysing the criteria for scenario definition (no trade-off); third workshop – impact assessment; fourth workshop – sustainability limits; and finally the fifth session – analysing the criteria (Helming et al., 2008).

The FORESCENE project combined analytical and participatory approaches to build a prototype model. To this end, it promoted a series of workshops involving European Commission directorates-general, stakeholders and experts in order to integrate knowledge on various environmental problems and priority policy fields, and to define essentials for integrated sustainability scenarios in term of goals and crosscutting policy measures.

There are also some projects where the identification of driving forces and scenario development were based purely on qualitative analysis and expert judgment. Examples of this are EUruralis (Klijn, 2005) and Scenar2020 (Nowicki et al., 2006).

Land use analysis

Analysis of the current land use maps is an important tool for understanding the behaviour of land use dynamics in the BSC, in order to establish rules that will reflect this behaviour in the future. The main land use categories represented in the BSC are croplands, followed by forest, crops/natural vegetation and grassland. These are also the most dynamic classes, since the largest flows were detected between them. The increase in forest is mainly due to land taken from crops/natural vegetation and grassland. Forest areas are increasing mainly in the northern part of the BSC, as well as in the extreme west and south-west. In contrast, considerable deforestation is happening along a line running west to east across the middle of the BSC. Cropland areas have increased slightly, especially in the central, northern and western parts of the BSC, while they show a tendency to decrease in the east, in the south, and in a small region to the west of the centre. The changes in cropland areas seem to be related to intensification in suitable areas and abandonment in less suitable areas. Grassland is increasing mainly in the southern and eastern parts of the BSC, gaining areas mainly from forest. Elsewhere some grassland is being converted to cropland while some has been abandoned and transformed into shrubland. Built-up areas in 2008 have mostly remained the same as in 2001.

Quantification of land use scenarios – global to regional level

The limitation of global models is strongly associated with the low quality of spatial resolution at the global scale. However, global land use models such IMAGE 2.2 have been widely applied in European scenario studies and produce promising results for assessing the IPCC-SRES scenarios.

In this study the IMAGE 2.2 model was used to estimate the forest, grassland and cropland areas for 2025 and 2050. The method used to downscale land use demand is based on the simple assumption that all NUTS2 regions have the same growth rate as the more inclusive unit (IMAGE 2.2 regions: OECD, REF EE
and Former USSR). Based on this relationship land use can be disaggregated to the regional level and used as a demand for the land use demand module in the Metronamica model.

In all the scenarios, agricultural areas are expected to decrease during the first half of the period followed by a slight increase in the second half. Only the regional economic scenario BS ALONE shows an increase in crop areas over the baseline year, due to policies to maintain agricultural production. In the BS COOP scenario, spatial policies reinforce natural protected areas and, as a consequence, agricultural areas are abandoned and converted to natural areas. In the BS HOT scenario, energy is strongly based on fossil fuels, leading to a smaller increase in demand for biofuel crops.

Grassland (pasture and fodder) areas will increase in the first half of the period and decline during the second half, especially in BS COOP and BS HOT. The total grassland area in 2050 will be higher than in 2008 only in the regional scenario BS ALONE. In the BS COOL scenario the area of grassland will remain the same. The conversion of agriculture to grassland and grassland to other land use types is expected.

In all the scenarios, forest areas tend to increase slightly until 2025 and subsequently decline until 2050. The BS ALONE scenario shows relatively minor changes in forest area. In BS HOT the forest area declines much more than in the other scenarios, due to major landscape changes influenced by urban sprawl and abandonment of agriculture.

In this report, we present the calibration for the selected regions. Furthermore, regions known from previous projects were also included in the calibration process. The information available for these regions will lead to a better understanding of the calibration process. The aim was to calibrate the application with a selection of regions that best represent the landscape of the entire BSC. Neighbourhood rules, suitability maps and zoning maps were developed based on historical land use analysis, scenario storylines and expert knowledge. Assessment of the calibration results shows that they are satisfactory. Finally the BS HOT scenario was run for the selected regions in order to test the performance of the model in the spatial allocation of land use demand. The results were satisfactory, demonstrating that land use patterns may differ somewhat in a particular scenario due to the regional contrasts present in the BSC. An example is the scenario for the Former USSR in which land use changes are much more moderate than in the REF EE and OECD regions during the same period.

Up to this point, the storylines have been translated into quantitative scenarios at regional level: 214 NUTS2 regions have been allocated their land use demands for 2025 and 2050. The next step will be to translate the scenarios at a spatially explicit level (1 km x 1 km) for the entire BSC using the Metronamica model (forthcoming enviroGRIDS D3.8).

6 Conclusion

The main goal of this report is to present a qualitative and quantitative approach to the development of the enviroGRIDS scenarios. In the disaggregation method used, land use demands are estimated for each of three regions and are disaggregated at NUTS2 level. The assumption is made that all the NUTS2 regions have the same growth rate as the more-inclusive unit. The results demonstrate certain limitations associated with the low quality of spatial resolution at the global scale, which severely constrains detection of the diversity of regional conditions affecting land use changes. Small inconsistencies can be found when the IPCC-SRES storylines are compared with the regional land use changes for the BSC. However, in spite of its coarse resolution, the global model is widely used to quantify storylines and it was demonstrated in previous studies to be a promising approach for translating global scenarios at regional level. The disaggregation of land use demand from IMAGE 2.2 to regional level makes it possible to assess landscape diversity based on the IPCC-SRES scenarios for the BSC regions. The IMAGE model can be downscaled to obtain land use demand at the regional level but it is not useful by itself. The designation of allocation rules introduces local decisions based not only on the scenario storylines and expert knowledge but also on
historical land use patterns. The combined method used can fill the gap between the global and regional scales and consequently can translate the land use patterns spatially.

This report focuses on refining the land use scenario storylines and on quantifying the scenario storylines for the land allocation model: estimating the land use demands for 214 regions, assigning transition rules, and developing the suitability, accessibility and zoning maps. The calibration and validation of the selected regions show that the model is able to extrapolate the future land use for the BSC. The BS HOT scenario tested for those regions shows that land use demand estimated for 2025 and 2050 has been allocated correctly in almost all the regions.
References


Abbreviations and acronyms

AOS  Atmosphere-Ocean System
ATEAM  Advanced Terrestrial Ecosystem Analysis and Modelling
BSC  Black Sea Catchment
CA  Cellular Automaton
DDNI  Danube Delta National Institute for Research and Development
DEM  Digital Elevation Model
EE  Eastern Europe
EEA  European Environment Agency
EIS  Energy-Industry System
ESA  European Space Agency
ESRIN  European Space Research Institute
FP7  Seventh Framework Programme of the European Union
GDP  Gross Domestic Product
GHG  Greenhouse Gases
IMAGE  Integrated Model to Assess the Global Environment
IPCC-SRES  Intergovernmental Panel on Climate Change – Special Report on Emissions Scenarios
IUCN  International Union for Conservation of Nature
MCK  Map Comparison Kit
MODIS  Moderate Resolution Imaging Spectroradiometer
NUTS  Nomenclature of Territorial Units for Statistics
OECD  Organisation for Economic Co-operation and Development
PRELUDE  PProspective Environmental analysis of Land Use Development in Europe
RCM  Random Constraint Match
REF EE  Eastern European countries undergoing Economic Reform
RIKS  Research Institute for Knowledge Systems
RIVM  National Institute for Public Health and the Environment
SRES  Special Report on Emissions Scenarios
TES  Terrestrial-Environmental System
UMA  University of Malaga
UNEP-GRID  United Nations Environment Programme DEWA/GRID-Europe
UNIGE  University of Geneva
USS  User Support System
WE  Western Europe
WFA  World Fire Atlas
WP3  Work Package 3