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"Land cover is the result of land use at a certain moment in time"
(Mücher et al., 1994).

Executive Summary

The EnviroGRIDs project explores a data-driven view for environmental studies. The WP3 aims to construct contrasting environmental scenarios for the Black Sea Basin utilizing available datasets from multiple scales. Developing a Black Sea Basin wide application for characterising land cover in several time steps, 2000, 2025 and 2050 is the end target of the task 3.3.

This deliverable aims to present comprehensively spatial data, inputs, tools and method for constructing spatially explicit land use scenario.

From the past to the present, the Land Use models have a common point: to simulate the landscape dynamic for the future into multiple scales based on different coherent assumptions, they improve the understanding and sensitivity of key process of land use patterns. The Land Use models allow also to test the dynamics and behaviour of linked social and ecological systems, through scenarios building and analysis.

There is a wide range of different approaches of Land Use models, based on relatively complex theories and methodologies. These modelling systems have tended to apply ‘black-boxes’ producing highlighted maps. If for one side these models produce more robust results their application is restricted for academic purpose owing to the high level of complexity in the interpretation of data.

The reviewed state-of-the-art in Land use modelling offers ample sources of guidance for construction of spatially explicit scenarios in Black Sea Basin, and also a well accepted approach, the Integrated Assessment of Land Use Systems approach using models and scenarios, developed with interaction of stakeholders.

The review of modelling tools, developed and/or applied in previous projects, such as ATEAM, SENSOR, EURURALIS etc. reveals an ample choice of available models. Following a set of criteria for model pre-selection allowed focusing on four approaches for detailed overview and comparison: Land Change Modeller, CA_Markov, METRONAMICA and CLUE. The Land Change Modeller and CA_Markov were testing for certain functionalities on an area defined for model tested covering roughly North Bulgaria. The METRONAMICA and the CLUE model were explored using the tutorial material provided by the owners.

However final model selection remains an open issue. Despite the fact that the four models can generally fulfil the same application, they differ in terms of specific features applicability, like level of complexity addressed (modelled dimensions), information on model development, optimization of model input processing, price of purchase and functionalities for specific end-user needs, as policy-impact assessment.

Regarding the main land cover data input it is emphasised that remote sensing has greatly facilitated the automated or semi-automated production of geo-referenced land cover databases with a high spatial accuracy, which in addition can frequently be updated. The update however is less readily acceptable with the same precision in geo-location and discrimination capacity due to the high variation of vegetation conditions and atmospheric influences on the remote sensing images input for automated classification.

Following a comparative assessment of the latest global land-cover maps: MODIS Land cover type, GlobCover and GlobCorine it was deduced that at present these products are suitable for spatially explicit accounting of main land cover categories over broad areas, but do not allow for temporal changes comparison. Therefore, due to the inherent limitations in using current global land cover datasets, it would be wise to utilise multiple datasets, as recommended in the literature, to apply fuzzy logic and prior knowledge for enhancing the utility of the available maps to better represent Black Sea Basin land cover.

The statistical sources of land-cover, mainly FAO, national and European ones (as EUROSTAT) can be used for analysing land use change processes in temporal perspective, spanning the last five decades. Combining statistical sources with records on crops, and spatial probability maps on agriculture use intensity may allow for downscaling of certain land use functions of interest.

Main categories of thematic data needed for land use modelling as biophysical and climate datasets, protected areas and transport infrastructure were reviewed and first selection of sources are presented.

For optimal use of the available resources, the working team proposed a work flow starting with presentation of the global picture for the Black-Sea Basin using data covering the entire basin and

afterwards improve and calibrate the first output using local and regional datasets. Therefore presenting and assessing the global datasets covering the whole of the BSB in a harmonized dataset as well as a several land use models able to produce the future land use simulations is the central goal of this overview.

It is specified that main effort is focused on the application of the available datasets and tools and not the development of new ones. However the optimization and adaptation of these available tools and data may be equally needed due to the lack of perfect dataset or model. The spatially explicit land use scenarios should be developed according to specified scientific objectives of land use system analyses following an integrated approach.

The working flow is progressing according to the following steps:

1. Overview of land use models and projects

2. Selection of models to build integrated land use scenarios

3. Definition of the main inputs for the selected model

4. Collection and preparation of the data

5. Calibration and parameterization of the models

6. Results analysis and assessment of land cover changes for the different scenarios in Black Sea Basin.

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1 Introduction

During the last two decades a tremendous volume of studies on Land cover has been produced. The European Union (EU) funded Pan-European Land Use and Land Cover Monitoring - PELCOM project (FP4) was the first pan-European study for remote sensing aided mapping of land cover. Land cover was defined as "the attributes occupying a part of the earth's surface, such as human artefacts, crops, grassland, forests and bare soil, which can be 'seen' from a distant and so by remote sensing" and land use "man's activities which are directly related to the land" (Anderson et al., 1976). From strategic planning and policy-making perspective and at wide temporal and spatial scales land cover change mapping is especially needed for detection and characterization of the human (land use resulting) impacts on the ecosystems. Land use change processes are typically expressed as change of use, for example from cropland to residential; intensification of the same use, for example from arable croplands to production in greenhouses; extensification, the same use but over larger area or with less intense production regime; marginalization or loss of socio-economic viability of certain production processes, usually concomitant with intensification elsewhere and abandonment. All of these processes of change bring landscape transformation, a major concern for preserving European natural and cultural heritage.

An understanding of the implications of changes in land cover and land use is a fundamental part of planning for sustainable development. From one side, the transformation of land cover and land use by human action can affect the integrity of natural resource system and the output of ecosystem goods and services. From the other side, by careful planning, the development of new patterns of land cover and use can enhance the well-being of people (Millennium Ecosystem Assessment, 2005).

Modelling is one of the methods to analyze the dynamic of the land use system, moreover applying modelling tools has changed the scientific framework for analysis of land use systems, from more descriptive to more quantitative addressing both spatial and temporal dynamics. The dynamic land use modelling has stirred up in the last year's high importance not only into environmental research but also into a social and policy-making domains.

From the past to the present, the Land Use models have a common point: to simulate the landscape dynamic for the future into multiple scales based on different coherent scenarios (Kok, et. Al., 2007), they improve the understanding and sensitivity of key process of the land use patterns (Lambin, 2000). The Land Use models allow also testing the dynamics and behaviour of linked social and ecological systems, through scenarios building (Veldkamp and Lambin, 2001).

There is a wide range of different approaches of Land Use models, based on theories and methodologies relatively complex. These modelling systems have tended to apply 'black-boxes' producing highlighted maps (Koomen, 2007). If for one side these models produce more robust results their application is restricted for academic purpose owing to the high level of complexity in the interpretation of data (Allen and Lu, 2003).

The Land Use/Cover Change (LUCC) program is a joint project of International Human Dimensions Programme (IHDP) and the International Geosphere-Biosphere Programme (IGBP). This project was developed to improve the analysis and modelling of the land use change process and facilitate land management (Focus 1); analysis and explanatory factors and production of diagnostic models of land cover dynamics (Focus 2) and integrated and prognostic regional and global models (Focus 3) (Lambin, 1999). Its activities finished in 2005 and a new program called Globe Land Project (GLP)[1] was initiated. The GLP has been developing further land-change science based on the foundations generated by LUCC and other identical projects.

The major challenge suggested by the LUCC program was the consideration of a new group of LUCC models that are able to simulate the major socio-economic and biophysical driving forces of land use changes and the interaction at several spatial and temporal scales (Verburg, et al., 2006).

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[1] GLP Web-Stie, Global Land Project page, 2010 (URL: http://www.glp2010.org/)

The actual objectives of the research of land use system follow the integrated approach called Integrated Assessment of Land-use systems (Figure 1), in which the LUCC models and scenarios are developed with interaction of stakeholders (Kok, et. al. 2007). This approach follows the spatially explicit analysis, at different temporal and spatial scales involving policy-makers and stakeholders to define and develop plausible scenarios, in participatory way. There has been a shift from more physical and data driven approaches to more human decision-oriented approaches such as agent-based modelling (Veldkamp and Verburg, 2004). In this sense, as an essential component of this research field, it is possible to build a solid framework for a systematic validation of projections generated from land use change models (Kok, et al., 2007).

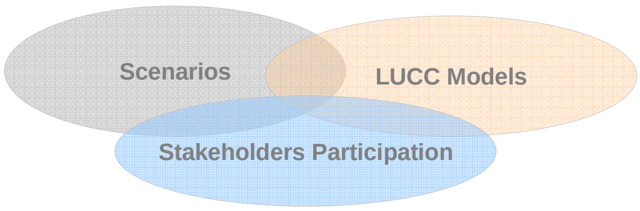


Figure 1: Integrated Assessment of Land Use System

As a consequence of the work of the last years, enormous quantity of tools and models have been developed resulting in a huge diversity and divergent approaches despite the global objective of Integrated Assessment of Land Use System (Kok, 2007).

Actually the concern of the scientific community is to bring closer the different methodology and models. Apart of consolidating the research it is necessary to integrate the different models, given that until this moment it was not possible to represent the land use complexity in one model.

1.1 Purpose and scope

The EnviroGRIDs project explores a data-driven view for environmental studies. The WP3 aims to construct contrasting environmental scenarios for the Black sea basin utilizing available datasets from multiple scales. Developing a Black Sea Basin wide application for characterising land cover in several time steps, 2000, 2025 and 2050 is the end target of the task 3.3.

This deliverable aims to present comprehensively spatial data, inputs, tools and method for constructing spatially explicit land use scenario.

For optimal use of the available resources the working team decided to organize a work flow starting with presentation of the global picture for the Black Sea basin and afterwards improve and calibrate it using local and regional datasets. Therefore presenting and assessing the global datasets covering the whole of the BSB in a harmonized dataset as well as a several land use models able to produce the future land use scenarios is the goal of this document. It should be specified that main effort is focused on the application of the available datasets and tools and not the development of new ones. However, the optimization and adaptation of these available tools and data is equally needed due to the lack of perfect dataset or model. The spatially explicit land use scenarios should be developed according to the above specified LUCC scientific objectives of land use system analyses following the integrated approach. Moreover, taking into account the above mentioned research challenges, it is recommendable to integrate the different methodologies and models for developing the land use spatially explicit scenarios.

In this sense, to achieve the objective, the first step is to present a brief review of the main projects that have addressed such issues already. The second step is to present a brief review of land use model option. The third is to present the modelling processes, the fourth is to analyse and review the data that is available for the Black Sea Basin taking into account the mains gaps.

EnviroGRIDS will be the first project to develop land use spatially-explicit scenarios for all Black Sea Basin. The countries that are part of the European Union are covered by previous projects, such as EURURALIS, SENSOR – Suitability Impact Assessment Tool (SIAT) and LUMOCAP (Dynamic land use change modelling for Common Agriculture Policy - CAP impact assessment).

1.2 Document structure

This report presents an overview of main themes related to land use modelling and required inputs. It starts with an overview of existing applications and review of past experiences. Then the process of land modelling with practical examples from a test site is presented, followed by an overview of latest available modelling tools. Afterwards the document presents a review of the available datasets to be applied as modelling inputs, including land-cover, thematic data as well as datasets useful for validation of the modelling output.

2 Overview of European land use scenario projects

This chapter aims to present existing projects and modelling frameworks, in accordance with the Integrated Assessment of Land Use System framework, described in the previous section: stakeholder participation, scenarios and LUCC models as well the driving forces, themes focused and horizon time (Annex I).

The range of projects presented, shows different modelling frameworks, scenarios approaches, and participation of the stakeholder on the scenarios development work. They offer experience, contributing with different elements of the framework and its application in policy relevant scenarios analysis.

Since 2004, appeared a vast number of research projects such as the Framework Programs from the European Commission that focus on land use system, changes, vulnerability and impacts of these changes.

The general aim of these projects is usually to focus on analyses of the land use changes and their potential environmental impacts, like, abandonment land, urbanization and deforestation. Additionally, there are various indicators analysed such as cropland for biofuel, biodiversity, carbon sequestration, soil degradation, employment in agriculture, etc.

2.1 Recent scenarios studies

Depending on the specific objective of the project, the main driving forces are identified considering the impacts on Land Use/Cover Change, and how they could be essential for current of future developments. These driving forces cover a range of socio-economic and biophysical factors, including demographic trends, spatial planning patterns, agriculture policies, climate changes and technology. The DPSIR framework (Driver, Pressure, State, Impact and Response) (OECD, 1994; EEA, 1998) represents the idea that we can distinguish between D) driving forces affecting the land use system by so called pressures (P) affecting its state in terms of bio-physical and socio-economic state (S). This can be seen as the impact (I) which has to be assessed from society leading the policy interventions (R). This framework was frequently applied on scenarios studies, such as in EURURALIS (Klijn et al., 2005), PRELUDE (Volkery, et al., 2008), SENSOR (Helming, et al., 2008), and FORESCENE; all helping to identify the major driving forces.

Regarding the scenarios studies, 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 to technological and economic development. The ATEAM (Shhröter, et al., 2004), PRELUDE and EURURALIS follow the IPCC-SRES reference scenario.

The 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 scenarios (A1) and medium priority (A2) based on an interpretation of the four SRES reference scenarios. The interpretation includes the definition of the range of driving forces for each land use type in Europe (Schröter, et al., 2004).

The EURURALIS uses as a starting point the IPCC-SRES and various related projects, such as Advanced Terrestrial Ecosystem Analysis and Modelling -ATEAM. Under this approach four scenarios were built: A1 – Global economy; B1- Global co-operation; A2 - Continental Markets and B2 - Regional Communities (figure 2). The vertical axis represents the global as opposed to more regional approach and the horizontal axis represents an open market compared with the higher level of intervention and regulation by governments (Klijn et al. 2005).

Figure 2: EURURALIS scenarios

In the PRELUDE (EEA) project, some parameters have been quantified based on the IPCC-SRES scenarios parameters or on ATEAM scenarios studies. However, when the descriptions of stakeholders are not well-suited with IPCC-SRES scenarios, the parameters were adjusted based on the expert judgment and observed data of past and recent trends (Volkery, 2008).

In the SENSOR project, three baseline scenarios were developed: a reference scenario, which is largely business-as-usual but with adjustments based on expert-judgments and two contrasting scenarios for high and low growth options (Helming, et al., 2008).

2.2 Stakeholders participation

Usually, the policy makers and stakeholders are involved to define and take part in the development of plausible scenarios, according to their interest and perspective.

In the case of PRELUDE (EEA, 2005) since the beginning of the project, a diversified panel composed by thirty specialists participated in the scenarios development involving researchers, representative groups of interest and general public. Different interests and perspectives were included. The stakeholders groups, modellers and experts have been engaged in interactive and creative process to provide the input into the scenario development. This process involved the development of qualitative storylines based on exhaustive discussions about key uncertainties and underlying driving forces.

Also in the SENSOR project, a Framework for Participatory Impact Assessment (FoPIA) was developed (Morris et al. 2008), involving national, regional and local stakeholders for assessment of land use policy impacts. This framework 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 discursive space for the exchange of knowledge and also, aiming at producing knowledge about the potential application and consequences of proposed policy changes. This framework involved five stakeholders workshops with the following structure: first workshop – refining the scenarios, second workshop - analyzing the criteria for scenario definition (no trade-off), third workshop - impact assessment, fourth – sustainability limits, and finally the fifth session - the analysis of the criteria (Helming, et al. 2008).

The FORESCENE project included a combination of analytical and participatory approaches, conducted to build a prototype model. To achieve this objective, it promoted a series of workshops involving DG's, 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 cross-cutting policy measures.

In the PLUREL (Zasada, et al. 2007) project, the FoPIA approach was also used, but in methodological terms it was based on Multi Criteria Analysis. In this project regional stakeholders including researchers and practitioners were involved.

The ATEAM – Advanced Terrestrial Ecosystem Analysis and Modelling (FP5) project aimed to assess the vulnerability of human sectors relying on ecosystem services with respect to global change. The ATEAM assessment process was formed by a 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 the decision-making of stakeholders. The stakeholders participated in a number of activities, including interviews and questionnaires, to identify the scientific information needs, as well as, workshops that were organized for communication and to trigger discussions between stakeholders (Schröter, D. et al. 2004)

There are also some projects where the identification of driving forces and scenarios development includes just the qualitative analysis and expert judgment. Examples of this are the EURURALIS (Klijn, 2005) and the Scenar2020 (Nowicki, P. et al., 2006) projects.

2.3 Modelling approaches

Different advanced modelling approaches have been developed to successfully address the above mentioned research questions. The LUCC models application cover different scales, ranging from the very local to the global extent, different spatial resolution and underlying concept of different thematic issues.

One of the major focus area of LUCC program is the development of integrated models and the prognostic regional and global models. In general, LUCC models can play a role (Verburg et al, 2006):

- As a learning tool to formalize knowledge: Models are applied to analyse the sensitivity of the key variables and other variables that identify the most important mechanism that could not be identified form field observation.
- In communication between researchers: to find ways to express oneself that are accepted to all disciplines involved.
- As a communication and learning environment tool for stakeholders, exploring possible futures developments in the land use-system exploring “What-if” scenarios and the visualization of alternative land use configurations that may be the result of policy decision or development in societies.

There are several studies that provide a good overview of the modelling tools currently available. For example Briassoulis (2000) gives a very extensive discussion of the most common land use change models. The US Environmental Protection Agency - EPA (2000), and the European Environmental Agency - EEA (2008) provide overviews more focused on technical information about the models such as, geographical coverage, theme covered, data input, model outputs, limitation, strengths, etc.

Also Verburg (2006), presented the variety of modelling approaches discussing the main characteristics of models, the strength and weakness of current approaches and indicated the remaining challenges for the land use community (Verburg et al, 2006). The main characteristics analysed are spatial or non-spatial models, dynamic or static models, descriptive or prescriptive, deductive or inductive, agent-based or pixel-based and regional or global.

The first main characteristic is whether the model is spatial or non-spatial. The spatial models aim at spatially explicit representations of land use change at some level of spatial detail (could be raster or administrative units). In spite of the diverse approaches, the spatially explicit models share approximately the same structure (Figure 3).

In their model structure, a distinction is made between the calculation of the amount of change and the allocation of change. In both cases the calculation is made using various driving forces that provide the location and as well the amount of change.

The suitability map or preference map represents the suitability of the location for a specific land use based on the driving factors that influence the allocation of this land use type. This process is one of the most important components of the land use models and there are a diverse set of analytical processes to develop it. The CLUE-s (Verburg, 1999) model, for example, creates the transition map through the logistic regression method; meanwhile the CA_Markov (Eastman, 2003) suggest to use a Multi-criteria Evaluation (MCE) method to develop the suitability map.

Regarding the claim of different land uses, there are various approaches: the bottom-up in which the spatial dynamics and allocation rules determine the aggregated quantity of land use change; the top-down approach in which the quantity of change is based on a set of driving factors and is used as a constraint in the actual allocation process and a hybrid approach in which the land use requirements are influence by feedback for the allocation module to account for e.g. the land availability and changing land values (Verburg et al, 2006) .

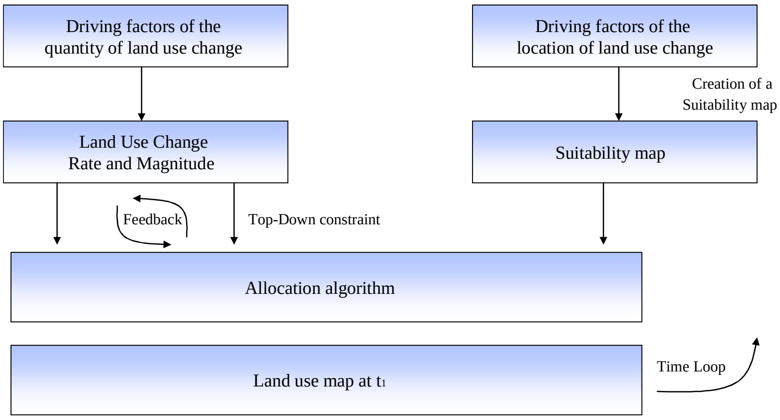


Figure 3: Generalized model structure of spatially explicit land use change model (Verburg et al, 2006).

The non-spatial models are focused on modelling amount and proportion of land use change, without specific attention for its spatial allocation.

The second characteristic is related with the temporal issue. The dynamic models focuses on the temporal dynamic of the land-uses system, through the competition between land uses, the changes from the past that cannot change in the future (for e.g. agriculture changed to urban cannot change back to agriculture) and fixed land use trajectories. They are more appropriated to be used for projections of future land use change. On the other side, the static models do not depend on a time series of an input data. This kind of models can be used to test our knowledge of the driving forces of land use change.

The third characteristic defines if the model is descriptive or prescriptive. The descriptive models aim at simulating the land use system based on the actual patterns and the projections of land cover/use change for scenarios conditions in a near future. The prescriptive models aim at the calculation of optimized land use configurations that best match a set of goals and objectives. In fact, the actual land use system is included as a constraint for more optimal land use configurations. The land use system is modelled in the way that best matches a series of objectives. The prescriptive models are useful for policy analysis since they provide a spatial visualization of the land-use patterns based on the constraints and objectives previously specified.

The fourth characteristic concerns the role of theory. The majority of the land use models are inductive, in which the model requirement is based on statistical correlations between land use changes and driving factors that provide insight into this change. The variables and relationships are identified trough various statistics, transition probabilities and calibrations runs. In contrast, the deductive approach is focused on the critical human-environment interaction, identified and concentrate the attention on the data required to explore those relationships.

The fifth characteristic is related with the simulated objects. In most part of spatially explicit models the unit of analysis is Pixel-Based representation. The unit of analysis could be an area of land, a polygon representing a field, a plot, census track or a pixel as part of raster-based representation. The land use changes are calculated for these objects, directly resulting in maps that show the changes in land-use pattern. Another group of models is represented by Agent-Based. The type of models is autonomous, they share an environment through agent communication and interaction, they give importance to the decision making process of the agents, the social organization and landscape.

The last characteristic is if the model is Global or Regional. The Regional models could be applied from the very local case studies to continental level. Those models vary in terms of resolutions that could be between $50m^2$ and 1000 km^2. The CLUE-s model, for example, is a regional model and was used in EURURALIS project, at 1km per 1km resolution, covering the EU-27.

The Global models are applied at continental and global scale. They have been developed mainly to analyse how land use/cover changes can play an important role in analyses of climate change, biodiversity loss, and agriculture production or world markets. Usually this models link sub-components representing population, economic activity leading to demands for agricultural products, technological and other themes. Another group of global models that address land use dynamics are global economy models. They explain the land allocation by demand supply structures of the land intensive sectors. Example of these models is the GTAP/LEITAP[2] (Purdue University) that was also applied on EURURALIS project to quantify the agriculture demand at national level.

As mentioned before, one of the main efforts of the LUCC program is the integration of Global with Regional models. Recently, many research projects focus on integrates the local and global models resulting in more sophisticated and promissory results.

An example at European level, the EURURALIS project use the CLUE-s model to allocate the land use on a grid level of 1km by 1km using the information taken from the Global models – GTAP/LEITAP (Macro-economic model) and IMAGE (Environmental model). The land use change is based on competition between different land uses and the use of spatial allocation rules (Klijn. J., et al. 2005).

The SCENAR2020 project is very similar in terms of cross sector modelling. The modelling framework is constructed under three economic models (LEITAP, ESIM, and CAPRI), one environmental model (IMAGE), and also the CLUE-s model to allocate the land use at grid level and three economic models (E.C., 2007).

For SENSOR – SIAT the NEMESIS model provide the future land use claims at country level and other sector models works at NUTS level. The Dyna-CLUE is used to bridge the gap between the outputs of NEMESIS and the input requirements of CAPRI and EFISCEN and to provide more information for the sustainability impact indicators. The Dyna-CLUE disaggregates the land use claims by country computed in NEMESIS down 1km by 1km grid units and also incorporates the spatial policies (Janson, T., et al., 2008).

The PRELUDE – EEA project (EEA, 2005), use the METRONAMICA (RIKS, 2009) model, which incorporates several simulation models that are linked using the Geonamica software environment. The MoLAND (Barredo, et al., 2003) and LUMOCAP (Van Dendel, et al., 2010) are also based on the same modelling framework.

The METRONAMICA model is a spatially-dynamic land use model that defines the potential land use change in the future taking into account the demands from several sectors.

[2] GTAP official Web-page, Purdue University: https://www.gtap.agecon.purdue.edu/

The range of models presented, shows different modelling frameworks, scenarios approaches, as well, participation of the stakeholder in the scenarios development work. They present experience, contributing with different elements of the framework and its application in policy relevant scenarios analysis.

3 Land cover modelling process

This chapter presents an overview including a brief description of step-by-step procedures related to data processing, model set-up, definition of assumptions of future change, and assessment of the predicted values.

The following steps are usually followed in land cover modelling process:

1. Data collection and preparation of inputs for modelling;
2. Match correspondence between different land cover maps (if needed to combine different sources);
3. Build matrix with land cover flows;
4. Elaborate flow accounts describing the processes of land cover change in the region of interest;
5. Indicators of land cover changes from land cover accounts for two years at least (for example 2001 and 2008: Total land cover 2001; origin of urban land uptake as % of land uptake; main annual conversion between agriculture and forest and semi-natural land in ha/year, etc.)
6. Analysis by class for defining spatial patterns (identification hotspots) of urban land; spatial patterns of agricultural land, spatial patterns of forest land, etc.
7. Identification of the most important driving forces for each land cover change.
8. Translation of qualitative storylines to quantitative input in land use / cover change models are frequently used for scenarios simulations, the translation of qualitative storylines into quantitative model conditions is often done on an ad-hoc basis.
9. Calibration runs for consistent data assimilation to represent the future states.
10. Validation of modelling results for model assessment including qualitative and quantitative analysis of the results

Several of these steps are illustrated in the next chapters with examples derived from Land Change Modeller on a test in North Bulgaria using CORINE LC as input.

3.1 Analysis of the land use patterns with LEAC method

The land use patterns could be analyzed trough the land use accounts methodology developed by the EEA and ETC-LUSI.

Since 2002, ETC-LUSI, together with EEA, is working on an accounting methodology for land use and ecosystem, the LEAC method (Weber, 2007). The EEA (No 11/2006) report ¨Land accounts for Europe - LEAC 1990-2000¨ presents the first application of this method, demonstrating detailed characterisation (including quantitative estimations) of major land-use patterns and changes in EU – the urban, agricultural, forest and semi-natural land-cover classes.

The LEAC method is based on the concepts of stock and flows as in conventional accounts (Weber, 2006). The key focus of land cover accounts is the understanding of the way in which stock of different land covers and uses are transformed over time. The transformations are classified into some 40 types of land-cover flows (Annex VIII). LEAC (1990-2000-2006) are derived from CORINE Land Cover (remote sensing product classification aided by expert image interpretation).

ETC-LUSI has developed different tools to query land cover data and land cover changes information in two different periods (1990 and 2000; 2000 and 2006). These tools work with an On-line Analytical Processing (OLAP) database, accessible through the Internet. The database is structured in accordance to a multi-dimensional approach for retrieving land cover using different analytical reporting units (LARU), however the system is not closed to other kind of data (population, nature protection, transportation, water assets). The LEAC tool allows for efficient processing and retrieval of data on continental scale and to perform spatial-based queries directly (without GIS). At this stage LEAC includes land cover data types, but with theoretically unlimited possibility to include other subjects, as areas of different rates of primary productivity and areas with different degree of habitat richness among others.

The land use accounts can potentially be used to help explore key issues related to questions about sustainable development. In this context the land cover account could provide a comprehensive picture of land cover and land use for Black Sea Basin from which information about trends can be derived and indicators of change constructed. It is a way to standardize classification of land cover, land use and causes (driving forces) of changes in land cover an land use (EEA, 2006). The LEAC method can be implemented as soon as two time-steps of land cover are available allowing for quantitative comparison.

3.2 Land Cover analysis of North Bulgaria testing site

Fist, a land cover legend should be selected among the available ones (Table 1) or modified according to our specific needs. The following legend was adapted from CORINE LC (Annex 9) for model testing in Bulgaria.

New class code	Label	CORINE LC code
1	Residential	111, 112
2	Industry	121, 122, 123, 124, 131, 132, 133, 422
3	Recreation	141, 142
6	Intensive agriculture	212, 213
4	Homogeneous Agriculture	211, 221, 222, 223
6	Heterogeneous agriculture	241, 242, 243, 244
8	Broadleaved/mixed forest	311, 313
7	Coniferous/young forest	312, 324
5	Grassland	321, 322, 323, 231
9	Bared land	331, 332, 333, 334, 335
10	Wetland	411, 412, 421, 423
11	Water	511, 512, 521, 522, 523

Table 1: CORINE 44 classes grouped into 11 categories for Land change modelling input

The transformations of each land cover over time as a transition matrix describe the transfers into and out the different cover categories between two time periods. This matrix is difficult to read and can be presented more usefully in the form of flow accounts.

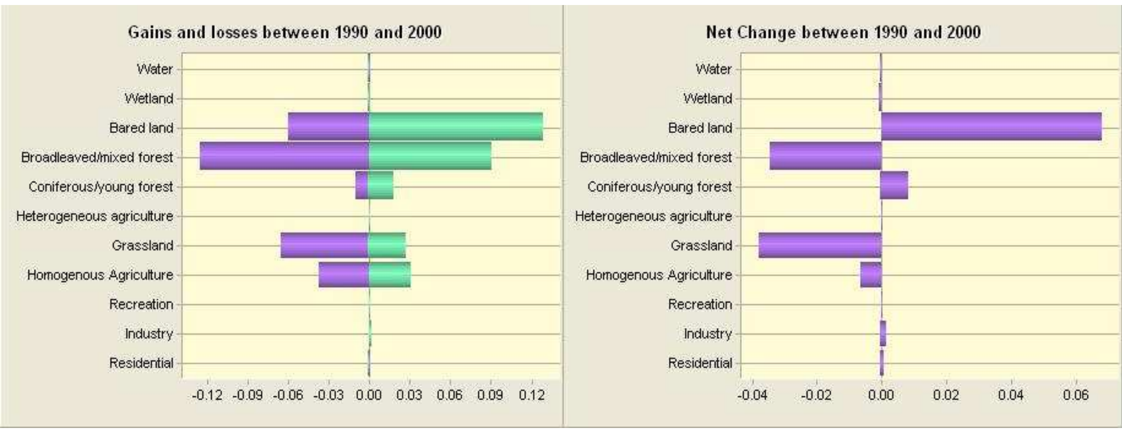


Figure 4: Gains and losses between land cover categories and net changes for Model testing area in North Bulgaria, graphics derived from LCM

The graphs emphasize the main transitions (Figure 4) e.g. bared land increase and broadleaf forest and grassland decrease in percentage of the entire area. These flows are mostly related with the following conversions:

FROM	TO	Land Cover Flow	Description
Homogeneous Agriculture	Grassland	LCF61 and LCF62	Withdrawal of farming – farmland abandonment and other conversions from agriculture activity in favor of forest or natural land.
Homogeneous Agriculture	Heterogeneous Agriculture	LCF4 and LCF6	Conversion between farming types and Withdrawal of farming without significant woodland creation
Heterogeneous Agriculture	Homogeneous Agriculture	LCF4 and LCF5	Conversion between farming types and conversion from semi-natural to agriculture.
Grassland	Homogeneous Agriculture	LCF52	Conversion from semi-natural to agriculture
Grassland	Heterogeneous Agriculture	LCF52	Conversion from semi-natural to agriculture
Grassland	Coniferous / Young Forest	LCF72	Forest creation, afforestation
Coniferous / Young Forest	Broadleaved / Mixed Forest	LCF73	Forest Internal conversions
Coniferous / Young Forest	Broadleaved / Mixed Forest	LCF73	Forest Internal conversions

Table 2: Main land transitions in North Bulgaria

The major change verified between 1990 and 2000 in Bulgaria was reflected mainly in the Broadleaved / Mixed Forest, Coniferous / Young Forest categories and Grassland (Table 2).

Over the 90`s the main changes occurred, mainly between the forest categories (LCF73) including Coniferous/ Young Forest to Broadleaved/Mixed forest land. A more discrete conversion is verified from the semi-natural land (Grassland) to agriculture (homogeneous and heterogeneous) (LCF521 and LC522).

Other important key flows identified in agriculture areas was the withdrawal of farming with woodland creation (LCF61) and the afforestation (LCF72) that consequently converts into Broadleaved / Mixed Forest.

The figure 5 represents all transitions in the test area, and emphasises the one selected for prediction. Related with agriculture areas, the largest change comes from homogeneous to heterogeneous. This type of flow is mostly related with conversions between arable land and permanent crops (LCF453 and LCF444), diffuse extension of set aside fallow land and pasture (LCF412), farmland abandonment in favour of natural or semi-natural landscape (LCF62) and extension of agro-forestry (LCF47).

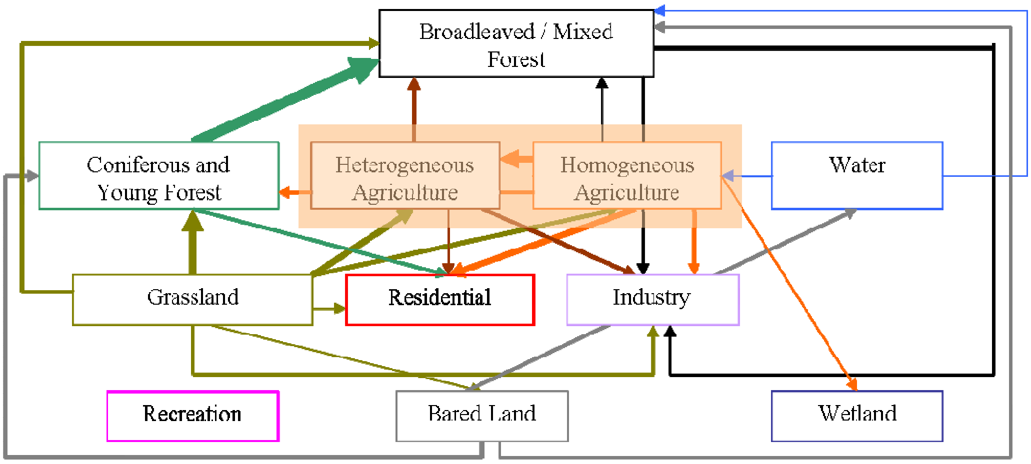


Figure 5: All land cover transitions in North Bulgaria

The urban residential sprawl in Bulgaria was very discrete comparing with forest and agriculture. The conversions occurred mainly from homogeneous and heterogeneous agriculture areas, grassland and coniferous/ young forest to residential. The sprawl of economic sites and infrastructure was verified in general as an increase between 1990 and 2000, the only exception is the loss for the water category, eventually related extension of water surfaces resulting from the creation of dams and reservoirs (LCF81) or changes in land cover resulting from natural phenomena with or without any human influence (LCF9). Wetland register an increase between 1990 and 2000 eventually related with changes of land cover due to natural and multiple causes as rotation between the dry semi-natural and natural land cover types of LCF (LCF912) and coastal erosion conversion of all land cover types to intertidal, estuaries or sea and ocean (LCF93).

3.3 Land use scenario building

The land use scenarios will be built around regional storylines closely connected to well established global scenarios published for instance by IPCC and United Nations Environment Programme (UNEP). The different scenarios combine the assessment of changes in the bio-physical environment with simultaneous changes in the socio-economic environment. The activities proposed under this work package are divided in two sub-tasks:

a. Definition of scenarios in Black Sea Basin using available assumptions and estimated indicators on future socio-economic development paths

b. Assessment of land cover uses changes for different scenarios in the black sea catchments.

Usually few scenarios are considered including business as usual or trend scenario, extreme development scenario and sustainable development scenario.

An example is provided bellow in figure 6 (assumption of possible quantity of change) and figure 7 (resulting allocation of the change).

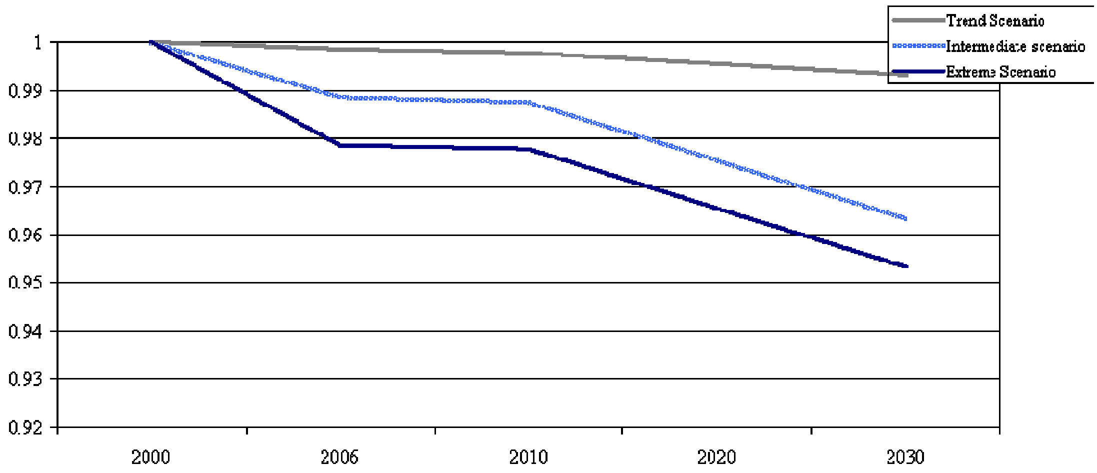


Figure 6: Example of quantification in different time steps of possible agricultural transformation from homogeneous to heterogeneous.

The business as usual scenario was constructed, applying the Land Change Modeller (LCM), set-up with CORINE LC data 1990 – 2000, and 2006 for validation. According to the trend most extensive land cover change within the period used for training was agricultural transitions from homogeneous to heterogeneous, as shown on figure 7.

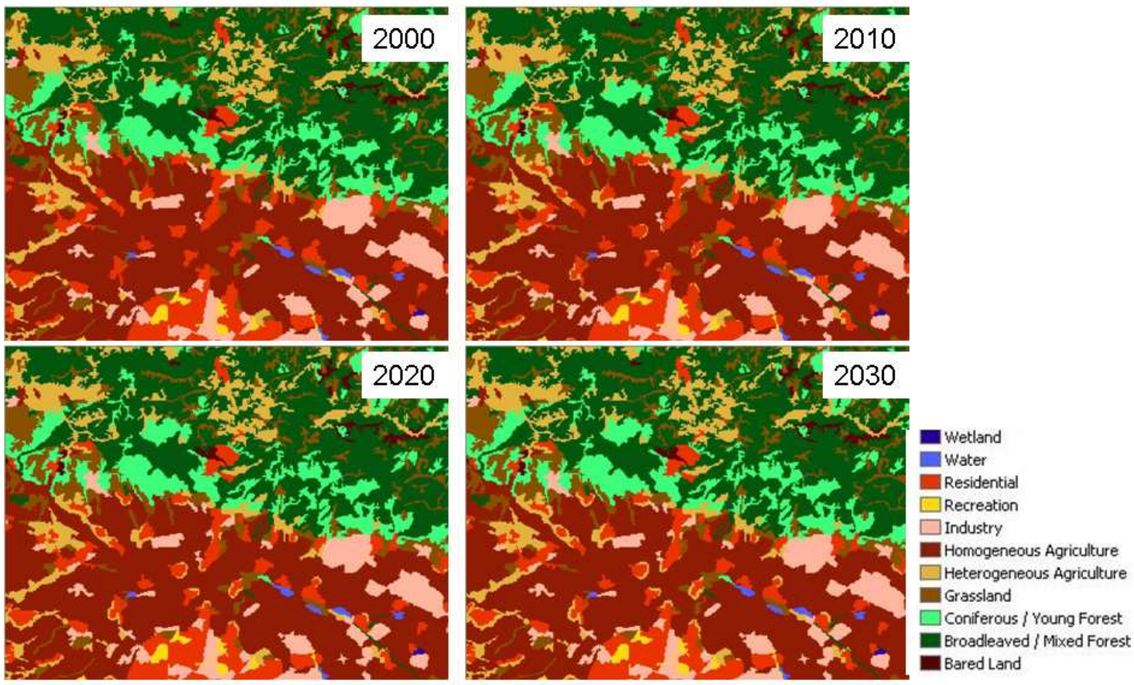
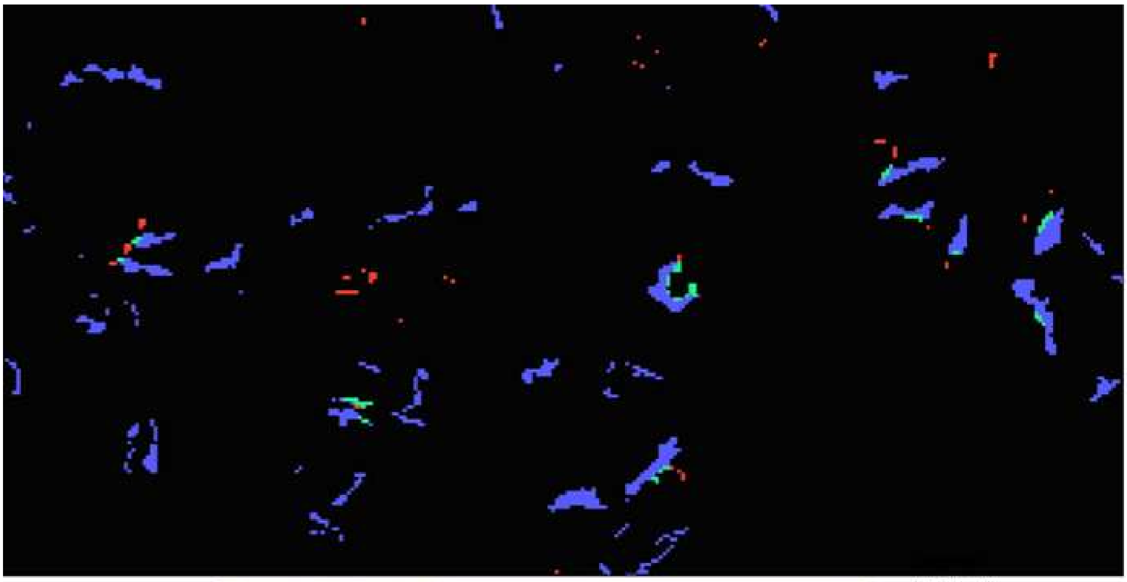


Figure 7: Land Change Modeler test in Sofia region Bulgaria. Business-as-usual scenario



calc4.vat:Rowid	calc4.vat:VAL	calc4.vat:	valp
0	0	6365955	/2 | 2 | 1 - Misses/3 | 3 | 1 -
1	1	436	4 | 6 | 6 - Hits
2	2	15867	4 | 4 | 6 - Misses
3	3	405	4 | 6 | 4 - False Alarms

Figure 8: Assessment of the Land Use Modeler results

The assessment of possible change in agriculture indicates that actually, the quantity of change between 2000 and 2006 was far larger than the history from 1990 and 2000. Once, the model takes into account the past, the prediction will be based on this amount and consequently will project the future. The quantity of “Misses” pixels is quite large because the model was not able to detect these changes.

4 Overview of Land cover models

4.1 Models options

The previous chapter was dedicated to the modelling characteristics and procedures. This chapter reviews briefly the modelling tools currently available to simulate spatially explicit land use scenarios that could be applied to the Black Sea Basin.

The models choice is basically dependent on the research questions that need to be answered and the data available. First of all, it is important to define the main criteria for land use model selection.

Spatial explicit models were identified through literature review. Although numerous models were identified, this review is focused only in models that take into account the following criteria:

- The model should be spatially explicit – the land use changes should be represented spatially at least 1km by 1km grid level
- The model should be able to predict at least till 2050 in the future, capture time slides, themes and driving forces in order to implement and assess the impact of multiple scenarios types and compare the outcomes
- The model should be chosen taking into consideration the data available for the whole Black Sea Basin.
- The model should be able to simulate and analyse multiple land use types

The land use models identified and presented below fulfil all these requirements. The next step was to check the main functionalities of each model in order to select the best candidate for developing the spatially explicit land use scenarios in the Black Sea Basin.

The review summarizes several of the leading spatially explicit models which explain the causes and consequences of land use dynamics and which are currently used to predict land use changes. More specific details are provided in the table that presents a short and general model description, adapting the structure of the template used by EEA (EEA, 2008): the model dimension, model development and the use of the model in environmental assessments (Annex II).

4.1.1 Land Change Modeller (Eastman, 2006)

The Land Change Modeller (LCM) for Ecological Sustainability for IDRISI 15.0 is a land cover change analysis and prediction model. This model provides a complete analysis of land change trough the creation of land change maps and graphs, land class transitions and trends. Regarding the prediction module, this model is able to create land change scenarios with integration of bio-physical and socioeconomic factors that influence the land use change. Usually, the biophysical factors integrated in the model are land use type, elevation, slope (derived form Digital Elevation Model - DEM), and hydrological features (distance to rivers and lakes). Regarding the socio-economic factors, the model could use infrastructure (e.g. roads) and demography (McConnell, W. J.; Sweeney S.; Mulley, B., 2004) (Annex III).

After having specified the variables which drive the type and transition to take place, the model will predict, for the specified future data the allocation of land cover changes. The LCM also includes the spatial zoning regulations, constraining or incentives, such as new infrastructure planning or corridor planning in order to make the model more complete.

Several studies used this model to predict land change dynamics. In Bolivia the LCM was implemented to study the impact of the roads development on land use and biodiversity conservation. In this study roads may grow based on the projected land cover change and the road information is fed-back into land change prediction. In Madagascar the LCM was used to identify a set of driving factors that can influence the various spatial patterns of agriculture conversion (Jiang, Z., 2007). The LCM was also used to analyse the land use changes in Mexico, trough a transition class matrix, built using regression techniques to understand the gains and losses for forest land use (Jaimes, N.; Sendra, J.; Delgado, M.; Rocha, W., 2008).

The major advantage of this model is the easy to use interface that could be used as a decision support tools for impact assessment in habitat and biodiversity. The output provided a spatial explicit scenarios and vulnerability maps. The vulnerability maps are generally chosen for land use impact assessment because it provides comprehensive analyses of change potential. A validation tool is also available to assess the quality of the prediction map in relation to a map of reality.

4.1.2 CA_Markov (Eastman, 1999)

CA_Markov is a combined Cellular Automata / Markov change land cover prediction procedure. It adds an element of spatial contiguity as well as knowledge of the likely spatial distribution of transition to Markov change analysis. The Cellular automata component allows the transition probabilities of one pixel to be a function of neighbouring pixels (Eastman, J., 2009). (Annex IV)

The CA_Markov can simulate changes prediction from several transition classes. The spatial-temporal Markov chain can be used to quantify the amount for each category in the landscape. Therefore, the location of change transition is based on a suitability maps and contiguity rule (Pontius, G., 2005). The suitability map for each transition are built through the MCE (Multi-criteria evaluation) method or logistic regression and include suitability variables (e.g. slope, elevation, hydrology) that describes the natural capacity of the land to support the transition in question and driver variables (e.g. infrastructure) that capture the historical issues that establishes some locations as being more likely to change than others (Eastman, 2005). The contiguity rule has the effect of predicting the growth of a category near locations where the category already exists for e.g. a pixel that is near an urban area is more likely to become an urban pixel than one pixel that is farther.

The CA_Markov was one of the three models applied in Sintra and Cascais to analyse the urban land use dynamics. The suitability map predicts the transition of categories built and non-built up areas. The probabilistic suitability map was built from urban areas for time 0, distance to urban center, and distance to main roads and slope. The quantity of each category through time are obtained by estimating variations in quantities for each category at t0 and t1, assuming the transition conditional probabilities are constant over time (Cabral, 2006).

In Mississippi Delta, U.S.A, the CA_Markov was used to model the past trends, to create future land cover scenarios and examine responses of coastal transitions to sea level rise and evaluating the effectiveness of management efforts (Shirley, et al., 2008).

For the Siberian Baikal region, spatial-temporal models and projections are developed for forest patterns and trends over Soviet and early post-Soviet. The CA_Markov coupled with a logistic model was applied to characterize the land use patterns and trends and to develop predictive scenarios (Peterson, et al. 2009).

4.1.3 CLUE Framework

The CLUE model is a tool to better understand the land use patterns and explore possible future change in land use at regional scale. The methodology integrate the spatially explicit analysis of relations between land use and its driving forces to a dynamic simulation technique to explore changes in land use under scenario assumptions.

The CLUE modelling framework include two different versions. The CLUE model (Veldkamp et al., 1996) is developed for continental/global application. It uses soft-classified data when high resolution data are not available, which usually happens in large extend areas. The CLUE-s model (Verburg et al., 2002) is based on high-resolution data in which each pixel only contain one land use type. This model has mainly been used in national case studies with a local to regional extent, and recently it is also possible to simulate high resolution land use change for larger areas (Verburg, 2004).

The land use location is based on a combination of the suitability of the location itself and the competitive advantage of the different land use types, which is a function of the demand. The demand is provided by exogenous models and can be based on different techniques ranging from simple trends extrapolation or advanced multi-sectoral modelling (e.g. EURURALIS, 2004, SENSOR-SIAT, 2004).

The input data supplied to set-up the model are the spatial policies and constraints including the parks, protected areas and agriculture areas; the land use transition succession; the land use demand that includes historical trends, scenarios and finally the location characteristics such soil, accessibility, etc (Verburg, P. 2004). (Annex V)

This model is one of the most used land allocation model in the globe with applications over the different regions and with different extent. The CLUE-s model was used for different purposes such as agriculture, deforestation and urban areas.

The CLUE-s model was used in various projects such as EURURALIS project (2004), SENSOR-SIAT (EU FP6 Integrated Project, 2004) and Scenar2000 (E.C., 2007 as a land allocation model to define potential land use changes in the future taking into account the demands from different sectors (e.g agriculture and economy).

4.1.4 METRONAMICA (RIKS, 2005)

METRONAMICA is a spatially-dynamic land use model developed to analyse the effects of alternative policy scenarios on the quality of the socio-economic and physical environment in cities regions or countries caused by autonomous development, external factors and policy measures. The system creates dynamics year by year land use maps as well as spatially explicit economic, ecologic and social indicators represented at high spatial resolution.

The main characteristic of METRONAMICA is the integration at three geographical levels.

The global level (one administrative or physical entity): refers to the global trends for population growth, activities per economic sector, and expansion of particular natural land uses.

The regional (N administrative or physical entities within the global level): on one side the national growth will be spread over the whole modelled area, and then it will allocate the interregional differences of activities and residents based on the relative attractiveness of each region.

The local (N cellular units within each regional entity): consequently the regional demands are allocated on the land use maps by means of cellular automata based land use. The changes in the land use at the local level are driven by four important factors (Delden, et al 2006):

- The physical suitability is the degree to which cell is fit to support a particular land use function and the associated economic or residential activity for particular activity.
- The zoning or institutional suitability for different planning periods specifying which area are permitted or constrained by a particular land use.
- The accessibility is an expression of the ease with which an activity can fulfil its needs for transportation and mobility in a particular cell based on the transportation system.
- Dynamic impact of land uses in the area immediately surrounding a location. For land use function, a set of spatial interaction rules determines the degree to which it is attracted to, or repelled by the other functions present in its surroundings. If the attractiveness is high enough, the function will try to occupy the location, if not, it will look for more attractive places.

The METRONAMICA has been used in various projects at European level. For example for EEA-PRELUDE, the METRONAMICA was used as a support to policy-making, to explore the impacts of scenarios on land use in Europe. There are several EU and non EU projects that apply the METRONAMICA as a land use allocation model integrated with several sector models.

The MoLAND (JRC) was developed to simulate future urban and regional development based on policy and zoning regulations, accessibility and suitability, to monitoring the sustainability and adaptation to natural hazards. This model integrates METRONAMICA as a land use model with other sector models (Economic, Demographic and Transportation sub-systems). The MoLAND model has been applied to an extensive network of cities and regions, contributing for e.g. to the evaluation and analysis of impact of extreme weather events (Genovese, E., et al., 2006) and to analyse the urban development and economy demand for European tourism region through land use change scenarios (Petrov, et al., 2008).

DeSurvey Integrated Assessment Model (IAM) (EC FP6 project) is a framework to develop policy support systems with the aim to support planners and policy makers that deal with regional development and desertification. This model is used for impact assessment of the various external factors and policy measures. This model improves the previous EU-projects such as MODULUS[3] and MedAction[4] Policy Support System (PSS) and contains 20 models integrated, with different spatial and temporal scales (e.g. climate, hydrology, water management, erosion, salinization, vegetation growth, land use, macro-economics, crop choice, irrigation). Similarly to the previous projects, the METRONAMICA is integrated as a land use module to allocate the demand for land use on the land use map. This model was applied on various case studies in Sahel, the Maghreb, Chile and China (Delden, et. al. 2008).

The LUMOCAP project was developed jointly by JRC, KU Leuven, Institute of Soil Science and Plant Cultivation - IUNG, Research Institute for Knowledge Systems - RIKS Netherlands. The Dynamic Land Use change Modelling for CAP (Common Agriculture Policy) aims to assess how different policy scenarios will impact land use and landscape in the 27 Member States of the European Union. The LUMOCAP PSS consist of a selection of models linked into a single integrated model that integrates bio-

[3] MODULUS official web-page, RIKS web -page http://www.riks.nl/projects/MODULUS

[4] MedAction official web-page, RIKS web -page http://www.riks.nl/projects/MedAction

physical and socio-economic factors. In LUMOCAP, the METRONAMICA land use model is also used to allocate the land use demands from the spatial interaction model at NUTS 2 level (Delden, et al, 2010).

4.2 Model Comparison

The review of modelling tools, developed and/or applied in previous projects, such as SENSOR, ATEAM, EURURALIS etc. reveals an ample choice of available models. Following a set of criteria for model pre-selection allowed to focus on four ones for detailed overview and comparison: Land Change Modeller, CA_Markov, METRONAMICA and CLUE. The Land Change Modeller and CA_Markov were tested for certain functionalities on an area defined for model testing covering roughly North Bulgaria. The METRONAMICA and the CLUE model were explored using the tutorial material provided by the owners.

However, the final model selection remains an open issue. Despite the fact that the four models can generally fulfil the same application, they differ in terms of specific features applicability, like level of complexity addressed (modelled dimensions), information on model development, optimization of model input processing, price of purchase and functionalities for specific end-user needs, as policy-impact assessment.

Key functionalities:

- **General purpose** – spatial planning and design or more strategic evaluation for policy-making
- **Modelling** (cellular automata, neural networks, logistic regressions)
- **Integrating multi-disciplinary themes** (integrating different drivers and factors in an interactive for reflecting scenario assumptions)
- **Multiple purpose applicability** (e.g. policy support, impact assessment, scenario assessment)

	CA_Markov Clark Lab IDRISI	**Land Change Modeler Clark Lab IDRISI**	**GEONAMICA – METRONAMICA (RIKS)**	**CLUE-S (WUR)**
Socio-economic factors		x	x	x
Biophysical factors	x	x	x	x
Spatial policies		x	x	x
Accessibility		x	x	x
Land cover change analysis		x	x	
Multi-scale modelling			**x**	
Pre-defined indicators		x	x	
Easy to use Interface		x	x	
Various transitions	x	x	x	x
Scenarios building tool			**x**	
Decision-Support System			x	
Total	2	8	11	5
Cust	Aprox. 500 euros[5]		27.000 euros	Free

[5] Academic license

Table 3: Model characteristics comparison

METRONAMICA is designed to better address the strategic issues of environmental assessment addressing processes at multiple scales. For example, main indicators such as country income would be introduced at global level e.g. country and downscaled to smaller units like municipalities on the basis of the share of main land use for ex, industry, forestry or agriculture. The user-friendly interface (Figure 9) allows to assess impact of policy-action, impact of future environmental, demographic and socio-economical changes etc. through the step-by-step scenario building tool.

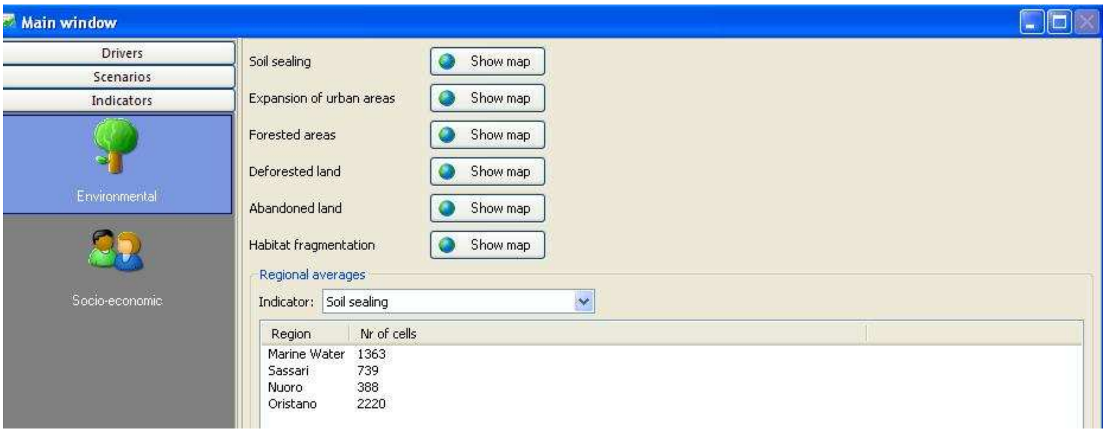


Figure 9: Metronamica Interface – Drivers; Scenarios, Indicator

LCM is able to address more local or region-specific spatial issues such as road and urban infrastructure designing, green and ecological corridor designing (Figure 10).

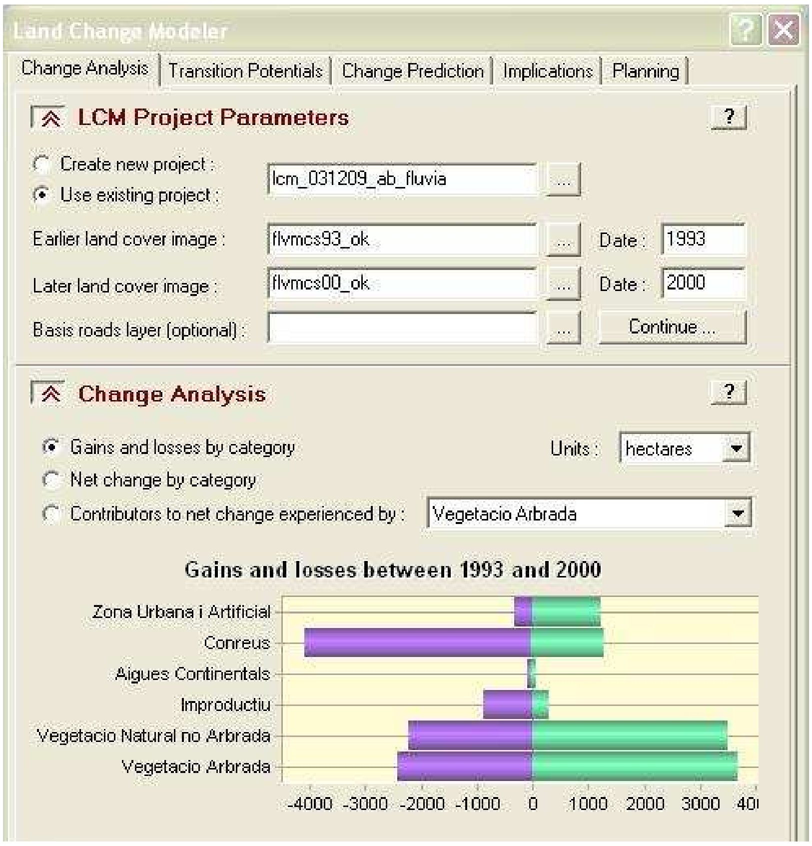


Figure 10: Land Change Modeller interface: Change Analysis, Transition Potential, Change Prediction, Implications and Planning

Cellular automata is a key functionality for modelling land use allocation. Three of the models METRONAMICA, CLUE and CA_Markov use the technique; LCM applies neural networks or logistic regressions.

METRONAMICA is the modelling framework able to address the widest range of complexity of thematic subject (factors and driving forces) for simulating land use in an integrated way.

5 Model Inputs

This chapter contains the description of the data required for spatially explicit land use models.

To run the model it is needed at least one year of land-cover map, however, it is much better to have there years spanning a meaningful period of changing land cover processes to allow for the proper model calibration and validation.

The land use modelling also requires a large number of socio-economic and biophysical factors that are considered to be important as potential drivers of the land use patterns of change. These drivers are usually represented by variables that describe demographic, economic and biophysical data.

Finally, the spatial policies contribute to indicate the areas where land use is able to change or not. The land use restrictions include for example the protection figures for forest, agriculture, natural areas and patrimony. On the other hand, the zoning maps show the areas that are designated for the development of specific land use types such urban development areas, or ecological corridors.

Data collection is normally the most time consuming aspect of the modelling. Socio-economic data and biophysical data are needed and there are many sources that must be consulted to populate the data set. All this data should be transformed and processed into a raster format to feed the models at regional level.

All grids should have the same grid size, projection, geographic system and extent.

A list of example of the data that can be used is found in table 4.

	Description	**Possible Source(s)**
Land use	Base year 1 Base year 2	MODIS Land cover type (the only product consistently updated during the last decade)
Demographic data	Population density Urban population density Rural population density	EUROSTAT, World Population Prospect
Economic data	Income or GDP	
Geographic Data	Proximity to centre city Proximity to roads Proximity to ports Proximity to major roads Proximity to main airports Proximity to rail stations	**Europe countries** GISCO **Neighbourhood countries** ESRI data
	Proximity main rivers and lakes	ECRINS
Biophysical Data Climate	Elevation Slope map Aspect map	ASTER-GDEM
	Soil quality map	Soil Geographical Database of Euroasia
	Precipitation	WorldClim

	Temperature	
Policy maps	Natural Protection areas, patrimony, forest areas. Development areas for e.g. urban extension or ecological corridors	European Common Database on Designated Areas – ECDDA
Administrative units	Country and smaller administrative unit boundaries	Gaul Administrative Units

Table 4: Possible data for the Black Sea Basin model inputs

The remaining of this chapter intends to present all possible spatial inputs with possibility for later update. A recommendation is elaborated about the strengths and weaknesses of the main inputs. These inputs should be further discussed and assessed before selecting the proper set for the actual land-cover simulations during the next phase of the project.

The global and pan-European land cover mapping and statistical reporting sources are the main input of interest for broad comparison of land use change processes across the Black Sea Basin (BSB) countries and also for future land cover simulations in the basin.

5.1 Land cover data

As mentioned before, the volume of literature on land cover analysis and change mapping is very extensive, and especially well developed for local and regional level e.g. focusing on sites, areas of special interest or entire countries. The studies applying globally or pan-European datasets are less common.

Generally land cover change can be expressed in terms of net change in areas per class e.g. areas of increased or decreased number of hectares. Statistical sources of land cover allow for extracting such net changes per country or smaller administrative units for which such data is collected.

5.1.1 FAOSTAT

Longest period (since 1961) of such data collection in a harmonized way has been reported by FAO and available for public use by FAOSTAT6. FAOSTAT contains data on areas of agricultural use at two sources, first as areas retrieved for harvested crops, and second as areas of land cover.

FAO code	Item
1717	Cereals
1804	Citrus Fruit
1814	Coarse Grain
1714	Crops Primary
1753	Fibre Crops Primary
1801	Fruit excl Melons
1737	Fruit Incl Melons
1738	Fruit Primary
1751	Jute & Jute-like Fibres
1732	Oilcrops Primary
1726	Pulses
1720	Roots and Tubers
1729	Treenuts
1800	Vegetables&Melons

[6] FAOSTAT webpage http://faostat.fao.org/default.aspx

Table 5: FAO´s categories of harvested crops

About 150 crop items are reported, within the categories shown on table nº 5. This source also contains information on the yield (tonnes per hectare per year) and total volume of crop produced (in tonnes per year). See example for Bulgaria on figure nº 11. The complete time-series were downloaded for most of the countries within the Black Sea Basin.

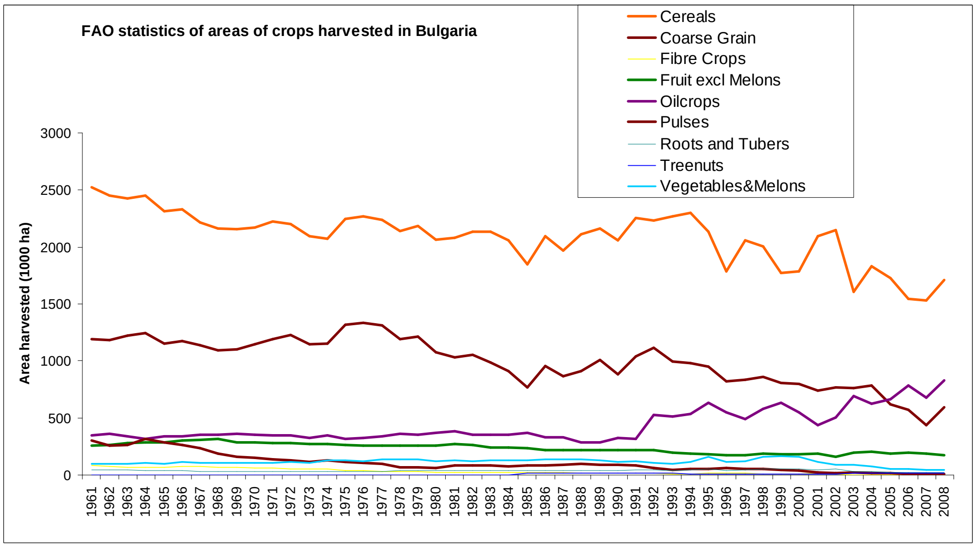


Figure 11: FAO annual statistics of 9 crop categories harvested in Bulgaria during the last 40 years

FAOSTAT contains also data on land cover for several categories of land as shown in table 6 reported over varying period of time. An example for Bulgaria is shown on figure 12.

FAO Code	ITEM
6600	Country area
6601	Land area
6610	Agricultural area
6611	Agricultural area irrigated
6620	Arable land and Permanent crops
6621	Arable land
6630	Temporary crops
6631	Temporary. crops irrigated
6632	Temporary crops non-irrigated
6633	Temporary meadows and pastures
6634	Temporary meadows & pastures irrigated
6635	Temporary meadows & pastures non-irrigated
6640	Fallow land
6650	Permanent crops
6651	Permanent crops irrigated
6652	Permanent crops non-irrigated
6655	Permanent meadows and pastures
6656	Permanent meadows & pastures - Cultivated

6657	Permanent meadows & pastures Cult. & irrigated
6658	Permanent meadows & pastures Cult. non-irrigated
6659	Permanent meadows & pastures - Naturally grown
6661	Forest area
6670	Other land
6680	Inland water
6690	Total area equipped for irrigation

Table 6: FAO´s categories of land cover types

The time-series were downloaded for several countries and in the next chapter the areas of land cover reported by FAO are compared to those extracted from EUROSTAT, and CORINE LC data.

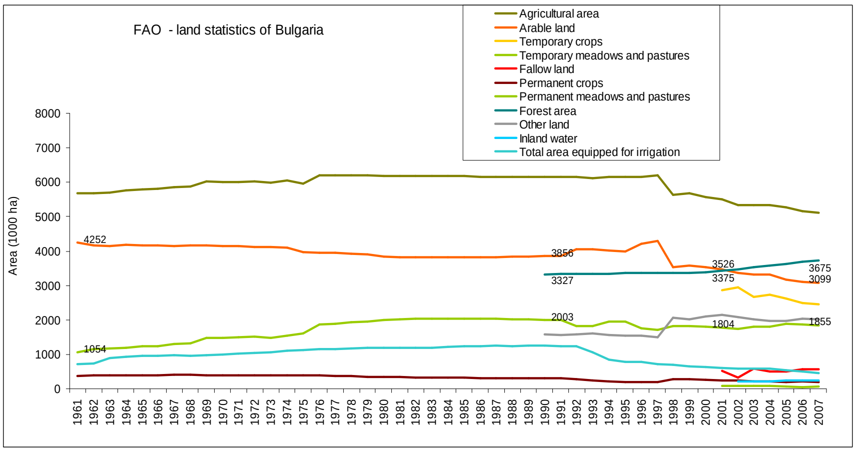


Figure 12: FAO´s land statistics for Bulgaria reported over the entire period of 1961 until 2007

Values of area (in ha) are shown for arable land, forest and permanent meadows and pastures for the years 1961, 1990, 2000 and 2006.

FAO datasets present the longest time-series of numerical data on land use and cover, however the reporting on country level results in certain limitations as country boundaries changed in the last century. Analysis of the change in areas of production and yield would allow to understand very well the processes of agricultural land use during the last half a century and in a development perspective. Comparing the areas of production with yield per hectare gives an indication of development degree (e.g. reflecting on technological innovations, irrigations, productivity improvements etc). On the other hand, intensity of use and cultivation brings environmental repercussions, e.g. impacts like nitrogen loads, CO_2 emissions, water depletion, water pollution, when environmental norms are not respected.

For land analysis in the Black Sea Basin using FAO´s statistics, a problem will be faced because all neighbourhood countries, but Turkey changed boundaries and so the complete time-series will have to be analysed as they were before they split into different states e.g. Yugoslavia and Union of Soviet Socialist Republics - USSR in the nineties and summed up to amount to the same original territory when they started reporting as separate states. This impedes a comparison of land cover change processes even at country level using FAOSTAT.

5.1.2 Remote sensing products of land cover

Prior to the collection of remote sensing imagery of the Earth there were few attempts of producing spatially explicit Pan-European land cover maps. The Dutch National Institute for Public Health and the Environment (RIVM) produced a ten-minute pan-European land use database by combining non-spatial statistical information with spatial information from available land cover maps. The collection of global coverage of medium resolution imagery from National Oceanic and Atmospheric Administration - NOAA´s AVHRR (eighties and nineties), NASA´s MODIS and ESA´s MERIS (for the last decade) enabled a number of rapid and enthusiastic attempts to produce more precise global maps, and in automatic reproducible way. Several Global and pan-European datasets are presented below in the order of their production.

5.1.2.1 Global Land Cover Characterization Data Base

The development of the Global Land Cover Characterization Data Base[7] (GLCC – Figure 13), a joint effort of the U.S. Geological Survey (USGS), the University of Nebraska-Lincoln (UNL), and the European Commission's Joint Research Centre (JRC) pioneered global land cover mapping. The first Version (1.2) of the Global database was released to the public in November 1997. This product was developed using AVHRR monthly NDVI composites from 1992 and 1993 to define cluster units. The clusters, as output of unsupervised classification were then labelled by expert knowledge. The final map was reclassified into six additional classification schemes including IGBP-DISCover and the USGS Land Use/Land Cover to meet individual needs of researchers and policy-makers.

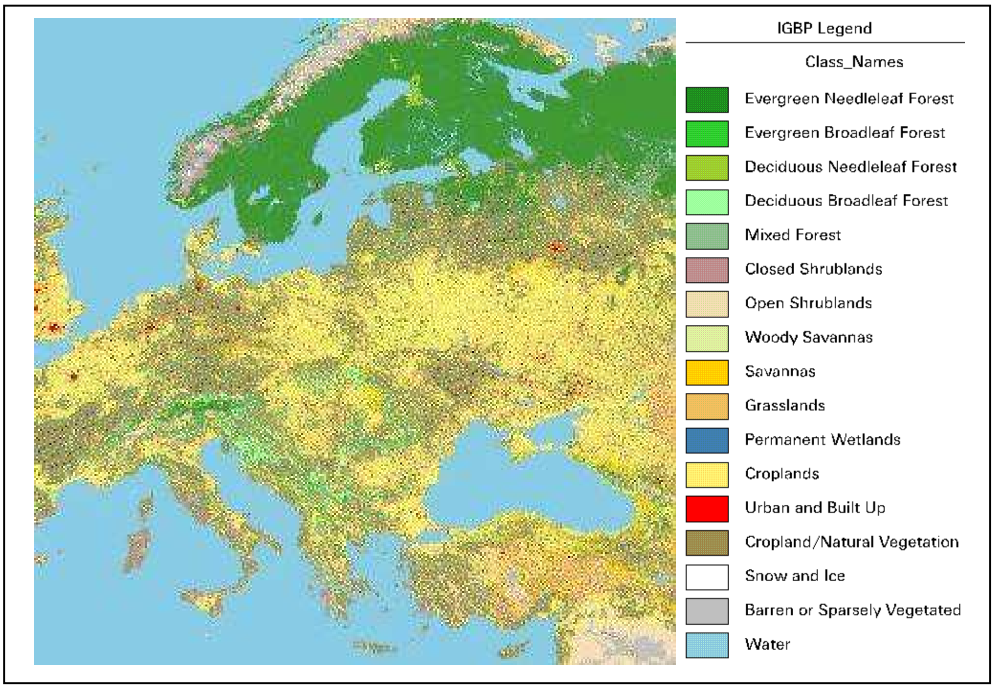


Figure 13: GLCC map 1992-3 of Central and Eastern Europe *(Source: USGS)*

For the European, particularly heterogeneous and fragmented landscape it was assessed by Mücher et al (2000, in the framework of the FP4 PELCOM project) that the GLCC has limited applicability. For example it underestimated forests over western and central Europe from 26.4% as identified by CORINE land cover to 7.8% as identified by GLCC. However, the authors stressed that the project was unique and enormous effort had been invested to produce the first global land cover database at a 1-km resolution in a consistent manner.

5.1.2.2 UMD Global Land Cover classification

The University of Maryland - UMD land cover product in 1 km spatial resolution used the longest period of satellite imagery input. It was released in 1998 by the department of Geography of the University of

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[7] Global Land Cover Characterization Data Base http://edc2.usgs.gov/glcc/glcc.php

Maryland (Hansen et al, 1998). Imagery from the AVHRR satellites acquired between 1981 and 1994 were analyzed to distinguish fourteen land cover classes in a modified IGBP scheme. The UMD mapping employed a supervised classification tree method in which temporal metrics derived from all AVHRR bands and the NDVI were used to predict class membership across the entire globe. This product is available at three spatial scales: 1 degree, 8 km and 1 km pixel resolutions. It is available at the Global Land Cover Facility[8].

5.1.2.3 PELCOM database

The PELCOM (Pan-European Land Cover Monitoring) database was produced in the framework of the FP4 project PELCOM, with the purpose of developing a method for automated land cover classification able to reproduce regular land cover updates. As an input were used NDVI maximum-value composites from year 1997 and daily multi-spectral AVHRR mosaics from years 1996 and 1997. The classification methodology developed in the PELCOM project was based on combining multi-spectral and multi-temporal AVHRR data in a stratified and integrative approach (PELCOM final report, 2000). Training samples for supervised classification were derived from selected homogeneous areas of the CORINE land cover database. Compilation of regional classification experiments, accomplished by the various partners in the project, resulted in a 1 km pan-European land cover database. It contains ten major classes of land cover: forest, grassland, arable land, permanent crops, shrubland, barren land, permanent ice and snow, wetlands, water bodies and urban areas.

The assement of PELCOM accuracy in reference with high-resolution images over Europe resulted in an overall accuracy of 69.2% which can be classified as a good result (PELCOM final report, 2000). Within the FP4 project, the PELCOM database has been also tested for assessment of future land cover scenarios, and also in various environmental and climate studies; in biodiversity research by RIVM, in large-scale inventories of biogenic emissions from forests by ARCS and in meteorological models by Meteo France. An important conclusion of the project was that medium resolution satellites (e.g. MODIS, MERIS) in combination with statistical and geographic ancillary data sources have a high potential for land cover change detection at the European scale (PELCOM final report, 2000).

5.1.2.4 Global Land Cover 2000

The Global Land Cover 2000 (GLC2000) project was an international initiative, coordinated by the Joint Research Institute (JRC) at Ispra, Italy. The objective was to provide a harmonized land cover database covering the whole globe for the year 2000 in 1km spatial resolution and in response to the needs of a number of global environmental policies, as well as for the Millennium Ecosystems Assessment.

The GLC2000 project was a bottom-up approach to global mapping, involving more than 30 teams for mapping 19 predefined regions (Bartholomé and Belward, 2005). The VEGA2000 dataset was the main input, it comprises 14 months of pre-processed daily global images (spanning from November 1999 till December 2000) acquired by the SPOT-VEGETATION instrument. A generally unsupervised classification was applied and then classes were defined following the hierarchical FAO-UNEP Land Cover Classification System (LCCS) applying the most appropriate classes for each region as defined by local experts to best describe the regional land cover characteristics and still maintain global consistency. The overall accuracy was assessed as 69% (McCallum et al, 2006).

5.1.2.5 MODIS Land cover type

Collection 5 of MODIS Global Land Cover Type MCD12Q1 (released in late 2008) is an improved methodology for global mapping using both MODIS-Terra and MODIS-Aqua instruments. It is derived from the original MODIS algorithm with substantial improvements but most important - higher spatial resolution of 500 m (compared to the previous 1 km). The Collection 5 product includes a new urban class definition that was produced independent of the main algorithm using methods specifically developed for global mapping of urban land cover (Friedl et al 2010). Also class-specific adjustments designed to improve mapping of wetlands and deciduous needleleaf forests were implemented. The annual maps are generated through supervised classification using a base algorithms (a decision tree), and ensemble

[8] Global Land Cover Facility http://ftp.glcf.umd.edu/index.shtml

classifications are estimated using boosting which allow the algorithm to derive estimates of class-conditional probabilities for each land cover type at each pixel (Friedl et al 2010). A method was developed also to stabilize classification variations year-to-year. Cross-validation accuracy assessment indicates an overall accuracy of 75%, with substantial variability in class-specific accuracies (Friedl et al, 2010). The MSD12q1 dataset includes five classifications (Table 7) the IGBP, Global ecosystems, UMD land cover, BGC biome scheme, LAI/fPAR biome scheme. Annual updates starting from 2001 are freely available at NASA´s Warehouse Inventory Search Tool (WIST)[9].

Class		IGBP (Type 1)	UMD (Type 2)	LAI/fPAR (Type 3)	NPP (Type 4)	PFT (Type 5)
0	Unvegetated	Water	Water	Water	Water	Water
1	forest	Evergreen Needleleaf forest	Evergreen Needleleaf forest	Grasses/Cereal crops	Evergreen Needleleaf vegetation	Evergreen Needleleaf trees
2		Evergreen Broadleaf forest	Evergreen Broadleaf forest	Shrubs	Evergreen Broadleaf vegetation	Evergreen Broadleaf trees
3		Deciduous Needleleaf forest	Deciduous Needleleaf forest	Broadleaf crops	Deciduous Needleleaf vegetation	Deciduous Needleleaf trees
4		Deciduous Broadleaf forest	Deciduous Broadleaf forest	Savanna	Deciduous Broadleaf vegetation	Deciduous Broadleaf trees
5		Mixed forest	Mixed forest	Evergreen Broadleaf forest	Annual Broadleaf vegetation	Shrub
6	shrublands	Closed shrublands	Closed shrublands	Deciduous Broadleaf forest	Annual grass vegetation	Grass
7		Open shrublands	Open shrublands	Evergreen Needleleaf forest	Non-vegetated land	Cereal crops
8	woodlands	Woody savannas	Woody savannas	Deciduous Needleleaf forest	Urban	Broad-leaf crops
9		Savannas	Savannas	Non-vegetated		Urban and built-up
10	Grasslands	Grasslands	Grasslands	Urban		Snow and ice
11	seazonally inundated or permanently	Permanent wetlands				Barren or sparse vegetation
12	Croplands and mosaics	Croplands	Croplands			
13	Unvegetated	Urban and built-up	Urban and built-up			
14	Croplands and mosaics	Cropland/Natural vegetation mosaic				
15	Unvegetated	Snow and ice				
16		Barren or sparsely vegetated	Barren or sparsely vegetated			
254		Unclassified	Unclassified	Unclassified	Unclassified	Unclassified
255		Fill Value	Fill Value	Fill Value	Fill Value	Fill V

[9] Warehouse Inventory Search Tool https://wist.echo.nasa.gov/~wist/api/imswelcome/

Table 7: Modis Land cover type. Five classification schemes

In the original MODIS land cover (collection 4 released in 2004) the mapping methodology was developed for NASA's Earth Observing System (EOS) MODIS land science team to frequently update dataset produced at 1 km resolution. It is produced by processing the 32-day database using decision tree and Artificial Neural Network (ANN) classification algorithms to assign land cover classes based on training data (McCallum, et al.. 2006).

5.1.2.6 GlobCOVER and GlobCORINE

The GlobCover is the most recent global mapping (Arino et al., 2008). It is an initiative of the European Space Agency (ESA) that was launched in 2005. It is led by an international network of partners including EEA, FAO, GOFC-GOLD, IGBP, JRC, and UNEP. The GlobCover map is produced in 300 m resolution (the most detailed global map until now) following FAO-UNEP LCCS scheme, and using ENVISAT-MERIS images of 2005 and 2006 as input. A considerable effort was made to improve MERIS data Geolocation accuracy. Accuracy better than 150 metres was requested by Land community and, as a consequence, Globcover can use MERIS only if such requirement is satisfied.

GlobCorine was derived from the same inputs applied for GlobCover but forcing another classification scheme, one adapted according to the European CORINE LC. It has been produced with Pan-European coverage (released in May 2010) covering the same period 2005-6 and with the same spatial resolution of 300 m. The verification of the GlobCorine database was carried out only in France, over the whole territory. The verification was done by visual interpretation by checking the selected Corine Land Cover classes (Urban, Forest, Agriculture, Wetlands). Improvements of particular classes were assessed, namely urban, given that certain deficiency was already shown in GlobCover. Also the forest class that was overestimated in the GlobCover has been reduced significantly in the GlobCorine database.

5.1.3 Assessment of the available land cover datasets for the BSB

The literature review on assessment of global and pan-European land cover maps show wide variations in the estimation of global land cover (PELCOM final report 2000, Giri et al 2005). This confirms that quantitative analyses of complex land cover types remain a challenging task. A comparative validation of three 1km products, the GLCC, GLC2000, and MODIS land cover have reported overall area weighted accuracies of 67%, 69%, and 71%, respectively (McCallum et al 2006).

The global and pan-European statistical and spatial data sources were compared in terms of areas for selected land cover classes in reference with verified land cover data in Hungary. The global spatial datasets of MODIS Land Cover (MCD12q1, 500 m), GlobCover2006 (300 m) and GlobCorine (300 m) are of special interest as they are the latest products as well as of highest spatial resolution. EUROSTAT statistics, and CORINE land cover were considered for their suitability as wider reference datasets to enable validation across different countries and years.

Generally, the areas of land cover reported for statistics can be considered to be more precise when looking at total area per class than the spatial datasets. The presence of mixed classes in the latter impedes the comparison of absolute numbers. Having in mind this limitation it was attempted however to assess which of the spatial datasets approximates most closely the reference data. For this purpose, only selected classes within a certain administrative unit were compared. It was not easy to define a reference source of well accepted precise land cover data, but most convincing reference data was found in a special report on setting up a system for National land and forest accounting in Hungary (downloaded from EUROSTAT[10]). It utilized several European sources of land cover areas that were analysed and finally presents the areas approved by the Hungarian government for year 2000. This Hungarian study was the only source of validated land cover for an entire country from the Black Sea Basin. The values were approved mainly on the basis of the more detailed Hungarian CLC50, as well as additional sources. CLC50 was produced according to the European CLC100 (scale 1:100.000 CORINE Land Cover, minimum mapping unit 25 ha,

[10] National land and forest accounting in Hungary, EUROSTAT Web-page http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/documents/environmental_asset_accounts/5BA6827BF4DC41E6E0440003BA9321FE

minimum width of linear features 100 m) but includes updated and enhanced details with satellite images taken in 1998-99. The report states that the CLC50 database (scale 1:50.000, minimum mapping unit 4 ha, 1 ha for lakes, minimum width of linear features 50 m) significantly improved the reliability of the land cover area estimations and emphasised its suitability for national purposes. In Hungary, the CLC projects were executed by the Institute of Geodesy, Cartography and Remote Sensing (FÖMI).

After selecting this most precise national data, for wider land cover datasets assessment it was then sought what might be the next best source, compared to the approved values for year 2000 in Hungary. Statistics extracted from EUROSTAT, CORINE LC and FAO's crops and land reports were compared for classes that match as definition between the different sources (Table 8).

CLC		Approved, 2000	LEAC 2000		Eurostat 2000		FAO land 2000	
code	name	Area, ha	Area, ha	% of approved	Area, ha	% of approved	Area, ha	% of approved
1.	Artificial surfaces	515712	547252	106.1				
21	**Arable land**	**4499800**	**4982977**	**110.7**	**4499800**	**100.0**	**4602000**	**102.3**
22	**Permanent crops**	**201300**	**213960**	**106.3**	**201300**	**100.0**	**201000**	**99.9**
23	Pastures	713900	681087	95.4				
23, 321	**Pastures and grassland**	**1307449**	**908044**	**69.5**	**1051200**	**80.4**	**1051000**	**80.4**
24	Heterogeneous agricultural areas	395589	397685	100.5				
2.	**Agricultural areas**	**5810589**	**6275709**	**108.0**	**5854400**	**100.8**	**5854000**	**100.7**
312	Coniferous forest	203374	100583	49.5				
311	Broad-leaved forest	1452873	1455719	100.2				
313	Mixed forest	80253	152461	190.0				
31	**Forests**	**1736500**	**1708763**	**98.4**	**1769600**	**101.9**	**1907000**	**109.8**
321	Natural grassland	593549	226957	38.2				
324	Transitional woodland/shrub	294097	287147	97.6				
32	Shrub and/or herb. veget. assoc.	887646	514104	57.9				
33	Open spaces with little or no veg.	9662	2313	23.9				
4.	Wetlands	127494	86448	67.8				
511	Water courses	76738	46945	61.2				
	Fish-pond	32000						
	Other water-bodies	104768						
512	Water bodies	136768	127685	93.4				
5.	**Inland waters**	**213506**	**174630**	**81.8**			**341000**	**159.7**
	TOTAL	9301109						

Table 8: Land cover data sources compared for Hungary.

The values in this table were introduced using the reference data of FÖMI for Hungary, the land cover areas for Hungary retrieved with the LEAC tool and the areas retrieved from EUROSTAT and FAOSTAT.

A good match between the three sources and the reference can be defined for some classes as arable land and forest and quite poor match between other classes even if under similar categories as pastures and grassland (sum of "natural grassland and pastures" in CORINE, 'Permanent meadows and pastures" in FAO). Comparing these areas for the common classes implies that EUROSTAT registers the most truthful values, closely followed by FAO, and also that CORINE LC shows high correspondence when classes are combined to approximate the aggregated categories of EUROSTAT and FAO. For mixed classes as mixed forest, the LEAC overestimates reality due to the more coarse resolution of the European CLC level 3. The Hungarian assessment emphasised that CORINE offers more realistic approximation than the statistical ones, namely due to the representation of mixed and transitional land cover types. For this reason, next, the global maps of MODIS MCD12q1 2006, GlobCover 2006 and GlobCorine 2006 were compared for selected classes using the European LEAC tool first for Hungary (Table 9 and 10) and then for three countries Austria, Hungary and Bulgaria (Table 10). All the values compared are for year 2006.

CLC code	name	LEAC 2006 Area (ha)	MODIS 2006 Area (ha)		GlobCORINE Area (ha)		GlobCover Area (ha)	
			Area (ha)	% of ref	Area (ha)	% of ref	Area (ha)	% of ref
1.	Artificial surfaces	561565	348755.9	**62.1**	216885	38.6	127573.1	22.7
2.	Agricultural areas	6220214	7613750	**122.4**	7460895	**119.9**	5970190	**96.0**
3.	Forests and semi-natural areas	2264596	1283251	**56.7**	1452069	**64.1**	3080370	**136.0**
4.	Wetlands	85843	4207.31	4.9	57369.73	**66.8**	2453.359	2.9
5.	Inland waters	177001	61327.98	34.6	123400.4	**69.7**	131543.8	**74.3**

Table 9: Areas of main land cover categories in Hungary from the latest Global maps

Looking at the aggregated categories corresponding to Corine Land Cover (CLC) level 1, it can be concluded that GlobCorine shows most balanced approximation of the five categories, with the artificial surfaces remarkably underestimated. All products underestimate this category, but MODIS achieves the best approximation and GlobCover the worst. GlobCover shows the best approximation of agricultural areas and inland waters. These aggregated approximations were derived after harmonizing the legends and grouping the areas of classes of the three products to match the reference Corine LC, as shown in figures 14 and 15.

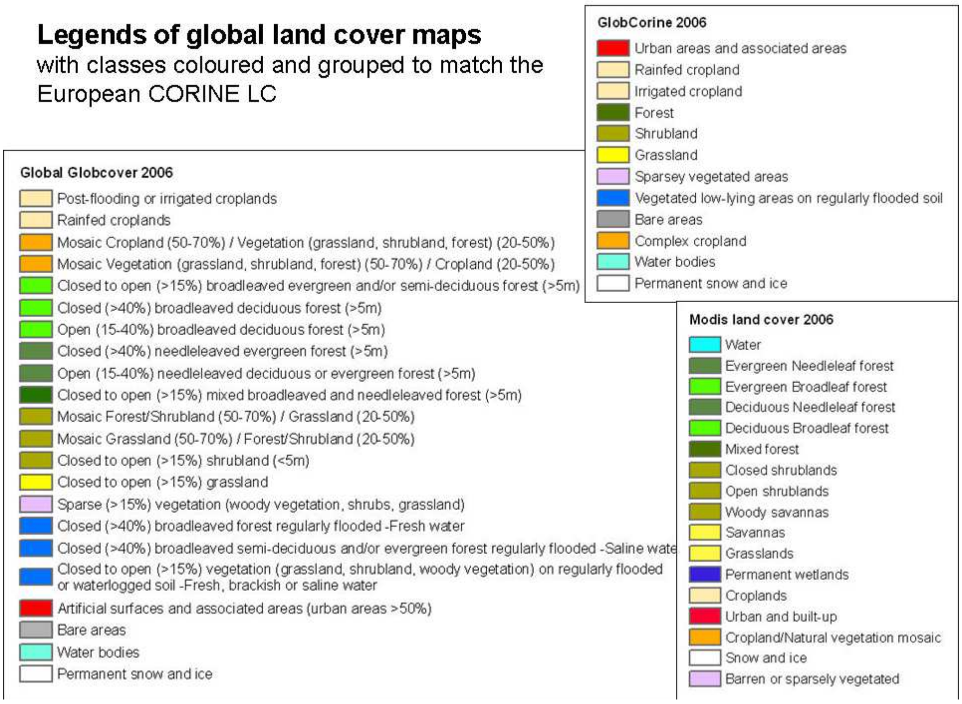

Figure 14: Legends of GlobCover, GlobCorine and MODIS Land cover matched to approximate the European CORINE LC

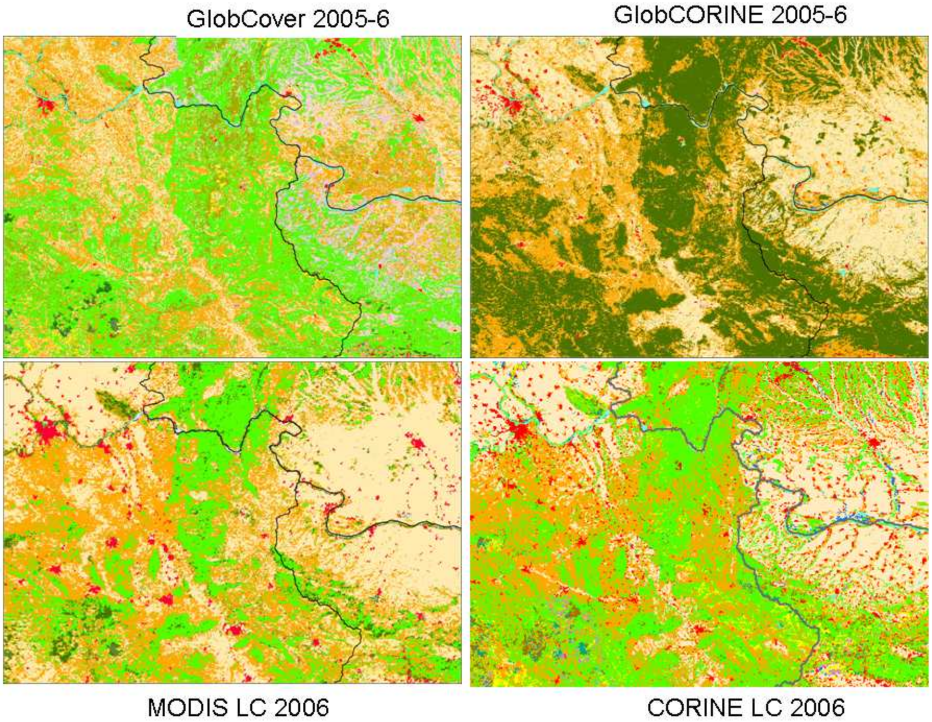

Figure 15: GlobCover, GlobCorine, MODIS Land cover and CORINE LC images with harmonized legends

CLC		LEAC 2006	MODIS 2006		GlobCORINE 2006		GlobCover2006	
		Area (ha)	Area (ha)	% of ref	Area (ha)	% of ref	Area (ha)	% of ref
1.	**Artificial surfaces**	**561565**	**348755.9**	***62.1***	**216885**	**38.6**	**127573.1**	**22.7**
21	Arable land	4938185	5462441	*110.6*	4918676	*99.6*	3150058	63.8
24	Heterogeneous agricultural areas	394221	2151309	545.7	2542219	644.9	2820132	715.4
2.	**Agricultural areas**	**6220214**	**7613750**	**122.4**	**7460895**	**119.9**	**5970190**	**96.0**
312	Coniferous forest	96508	48190.87	49.9			19241.24	19.9
311	Broad-leaved forest	1471971	944863.1	*64.2*			1668421	113.3
313	Mixed forest	152231	168034.8	*110.4*			20998.14	13.8
31	**Forests**	**1720710**	**1161089**	**67.5**	**1422931**	***82.7***	**1708660**	**99.3**
321	Natural grassland	226573	4142.912	1.8	20228.6	8.9	63878.83	28.2
324	Transitional woodland/shrub	315018	117525.6	37.3			202242.6	64.2
333	Sparsely vegetated areas	2295	279.0563	12.2	7605.005	331.4	1104374	48120.9
	Bared areas		214.6587		1305.071		1214.821	
3.	**Forests and semi-natural areas**	**2264596**	**1283251**	**56.7**	**1452069**	**64.1**	**3080370**	**136.0**
4.	**Wetlands**	**85843**	**4207.31**	**4.9**	**57369.73**	***66.8***	**2453.359**	**2.9**
5.	**Inland waters**	**177001**	**61327.98**	**34.6**	**123400.4**	***69.7***	**131543.8**	**74.3**

Table 10: Areas of selected land cover classes from three latest Global maps compared for Hungary

Looking at the particular classes one can observe the very huge difference between class definition and classifiers applied as well as influence of spatial resolution. MODIS MCD12q1approximates well artificial, arable, broadleaf and mixed forest, and underestimates tremendously wetlands, natural grassland, sparsely vegetated areas, and less – scrublands, coniferous forest and inland waters. GlobCorine reflects perfectly the arable lands (in terms of total area), also forest as total, wetlands and inland waters. GlobCover represent well total agricultural areas, broadleaf forest, transitional shrubs and inland waters. The three products underestimate too much the grasslands, but GlobCover least. The three also overestimate many times the heterogeneous agriculture which is however an effect of the spatial resolution, logically the bigger pixels of the three compared to CORINE's should encompass more mixed land cover types.

Finally for more objective comparison the percentages of approximating the reference LEAC stocks are shown for the three countries Austria, Hungary and Bulgaria (Table 10).

		MODIS Land cover (2006)			**GlobCorine (2005-6)**			**GlobCover (2005-6)**		
		Austria	Hungary	Bulgaria	Austria	Hungary	Bulgaria	Austria	Hungary	Bulgaria
1.	Artificial surfaces	47,9	62,1	43,6	37,0	38,6	42,7	20,8	22,7	39,8
21	Arable land	99,8	110,6	118,8	106,1	99,6	90,5	101,9	63,8	38,2
24	Heterogeneous agricultural areas	207,9	545,7	226,0	273,5	644,9	229,2	0,0	715,4	195,5
2.	Agricultural areas	99,0	122,4	128,6	119,5	119,9	110,1	43,6	96,0	67,4
312	Coniferous forest	0,0	49,9	13,0				445,7	19,9	22,9
311	Broad-leaved forest	2,4	64,2	330,3				78,0	113,3	767,5
313	Mixed forest	258,0	110,4	133,1				84,6	13,8	31,5
31	Forests	79,4	67,5	83,9	112,6	82,7	126,0	120,5	99,3	139,1
321	Natural grassland	71,5	1,8	33,9	71,5	8,9	5,3	39,3	28,2	6,5
324	Transitional woodland/shrub	0,0	37,3	56,3	31,9	0,0	6,3	0,0	64,2	48,7
333	Sparcely vegetated areas	0,4	12,2	0,9	61,8	331,4	18,4	294,5	48120,9	4165,2
4.	Wetlands	27,9	4,9	47,7	54,9	66,8	37,5	12,5	2,9	0,6
5.	Inland waters	87,4	34,6	36,0	100,8	69,7	78,8	92,5	74,3	85,3

Table 11: Land cover percentages from Global maps compared to LEAC 2006

The percentages from the three countries and the three land cover products give an impression about the strengths and weaknesses of each product in a more coherent way.

5.1.4 MODIS Land cover time-serie

The MODIS land cover time series from Collection 5 was downloaded and the different annual maps screened over known areas in the Black Sea Basin for first impression of the applicability of the time series for temporal changes analysis. The inspection as shown on figure 16 highlights major deficiencies: the lack of urban area change where such should be reflected i.e. around urban centres, the annual fluctuation of heterogeneous agriculture (cropland/natural vegetation mosaic) and of high altitude grasslands probably more related to annual variations of precipitation rather than actual land cover change.

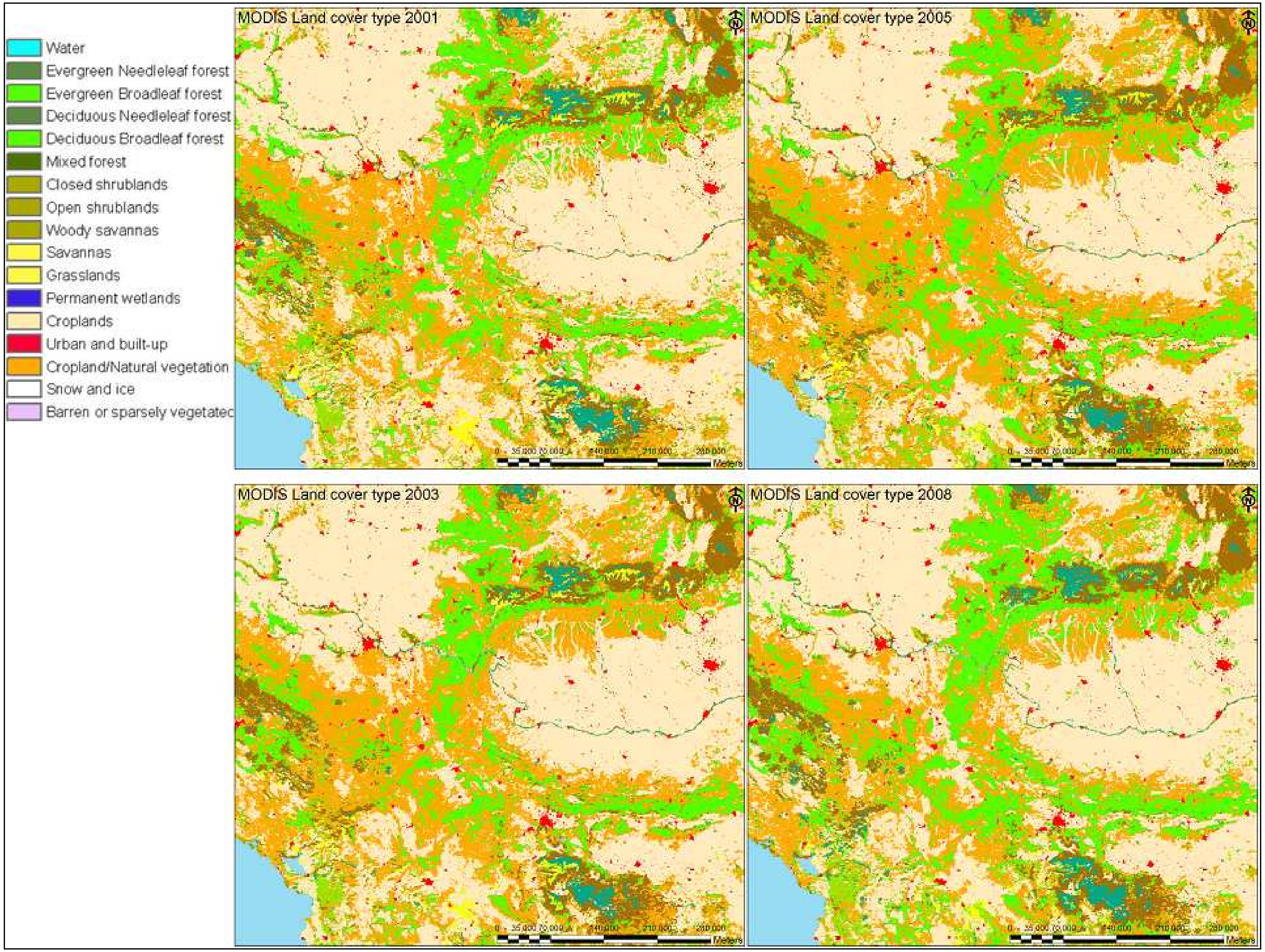

Figure 16: Modis Land cover time series, 2001, 2003, 2005, 2008

The mosaic maps of years 2001 and 2008 were also used to produce full land-cover change detection with the Land Change Modeller, over the entire Black Sea Basin and the general figure is shown bellow (Figure 17). However these land cover change results should be used for actual analysis and modelling of future changes only after validation for their truthfulness.

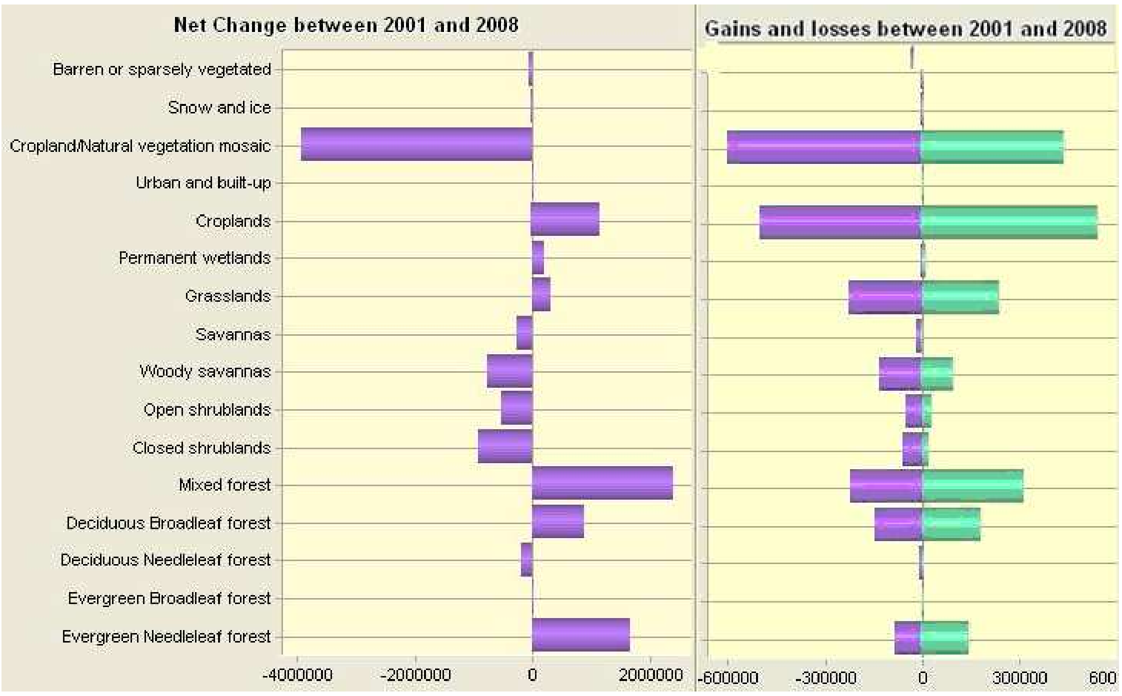

Figure 17: Land cover flows from Modis images, 2001 to 2008

As a conclusion, it should be emphasised again that only the statistical datasets allow for long-term temporal processes analysis, 5 decades until now, as aggregated per country or smaller administrative units in some cases. FAO is the only data source allowing to compare these processes throughout all countries. The spatial patterns for land cover and their dynamics are less readily comparable using one dataset. In static terms GlobCorine is the best product for countryside, water bodies and natural vegetation distribution analysis, GlobCorine in addition can help distinguish between different forest, and other natural vegetation types, but there seems to be gross exaggeration of sparsely vegetated areas. MODIS land cover type products reflect better the urban and agricultural uses, but underestimates forest and natural vegetation types. MODIS is reproduced annually and therefore may offer opportunities for improvement and multiannual land-cover comparison over the entire Black Sea basin, especially if calibrated and improved through use of local and more precise data sources.

5.2 Overview of thematic data

The majority of LUCC models include a component for mapping the “suitability” of land for transition from one cover type to another. The suitability map calculates the degree to which locations might potentially change in a future period of time (Eastman, et al., 2005).

The land use transitions, usually take place at location with the highest probability for the specific type of the land use at the specific moment. The favourite place is established through a set of explanatory variables. The biophysical and socio-economic factors describe the inherent capability of the land to support the transition in question and establish some locations as being more likely to change. Additionally, the interaction between the different actors and decision making processes establish the spatial land use configuration.

The suitability could include the monetary profit, cultural and other factors related with economic factors. Location characteristics depends also on the physical characteristics such as soil quality, altitude, but also household, community or administrative level can influence the decisions on land use location.

Social and environmental forces driving variables of land use change were identified subsequently by literature review.

5.2.1 Demographic data

The precise form and content of Demographic data input is to be defined depending on the selected land cover model. The most important characteristics of population aspects which are expected to play a major role in explanations of land change are is the distribution and the population growth. The conduct of demographic factors in land use change research is becoming increasingly sophisticated and demographic data essential.

The data provided from UNIGE WP3.1 rural and urban population, Census projections, Rural and urban population density should be considered.

5.2.2 Biophysical data

Apart from socio-economic drivers, which are determinant for land use changes, the biophysical factors, such, soil characteristics, climate, slope, vegetation, tend to define the natural capacity to land use change to vary among localities and regions (Lambin, et al. 2003). For example, biophysical limitations, such as steep slopes and difficulty of access provide the best conditions for the development of forest land cover. On the other hand, the extreme biophysical events, such as drought and forest fires, are usually inducing to long term land use changes.

These maps are essentially required for producing the suitability maps. As it was described before, the suitability map represents the suitability of the location for a specific land use based on the driving factors that influence the allocation of this land use type. The suitability maps are calculated from a set of explanatory variables that can be considered as predictive of the location of change. The suitability variables describe the inherent capability of the land to support the transitions.

Elevation, Slope, Aspect - Digital Elevation Model (DEM) – the digital elevation model (DEM) would be obtained from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) which was developed jointly by the Ministry of Economy, Trade and Industry (METI) of Japan and United States National Aeronautics and Space Administration (NASA). The ASTER-GDEM is a GeoTIFF format with geographic latitude and longitude coordinates and a 1 arc second (approximately 30 m) grid and it is georeferenced to the WGS84/EGM96 geoid. The accuracies estimated for the ASTER DEM were 20 m at 95% confidence for vertical data and 30 m at 95% confidence for horizontal data.

From the DEM, several maps will be derived such as Elevation, Slope (Figure 18) and Aspect.

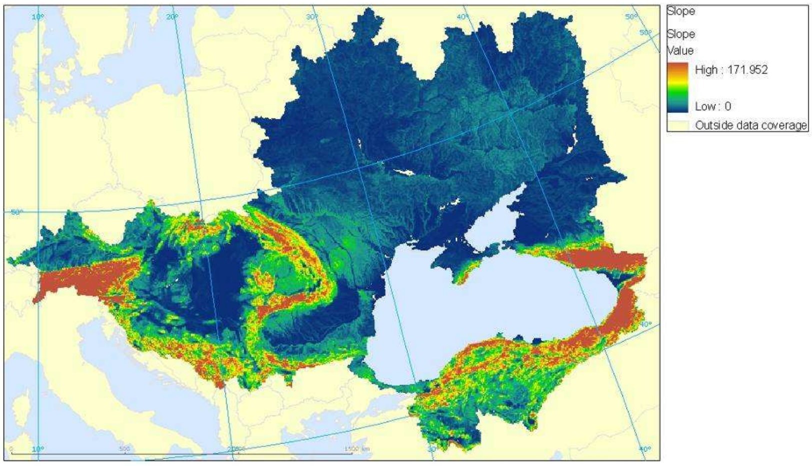

Figure 18: Slope

Rivers and lakes - European catchments and Rivers network System (ECRINS) have been developed by European Environment Agency (EEA). It is a fully connected system of watersheds, main rivers (Figure 19), secondary rivers (Figure 20), lakes (Figure 21), monitoring stations, dams from the JRC CCM 2.1 and many other sources.

The ECRINS provides some landscape characteristics such as lakes and rivers that influence the land use location. These variables are usually represented by their proximity. For example, the agriculture land is more likely to get allocated in coastal plains and near to the river.

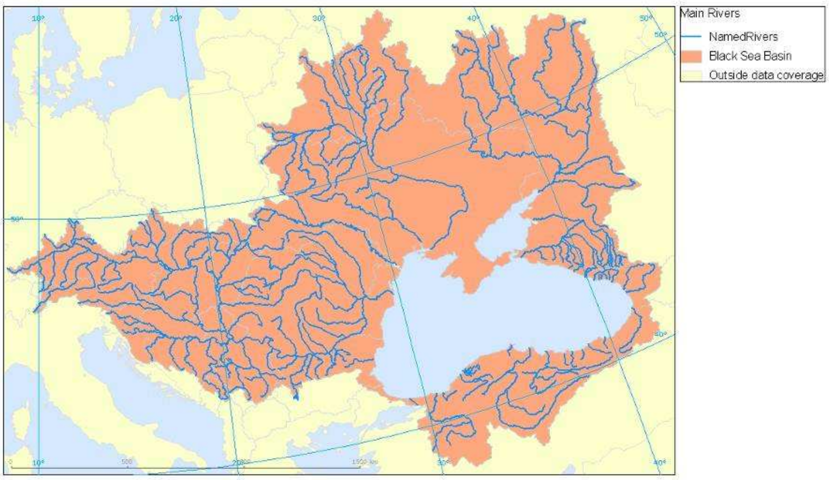

Figure 19: Main Rivers – ECRINS

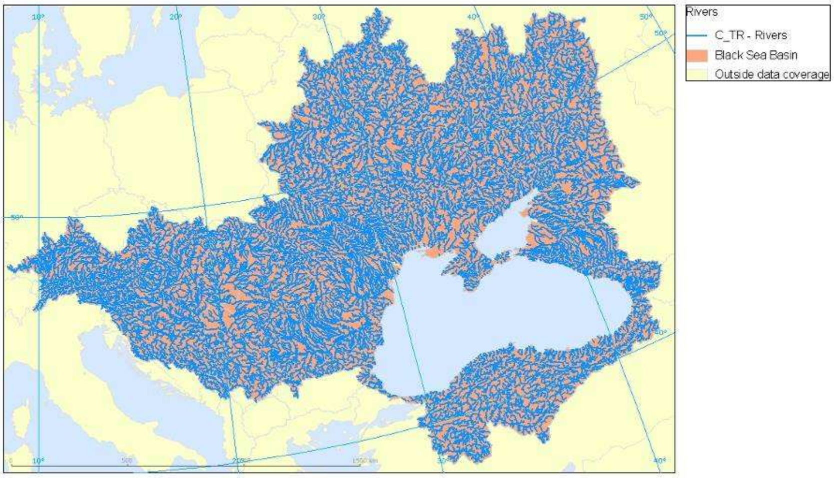

Figure 20: Secondary Rivers

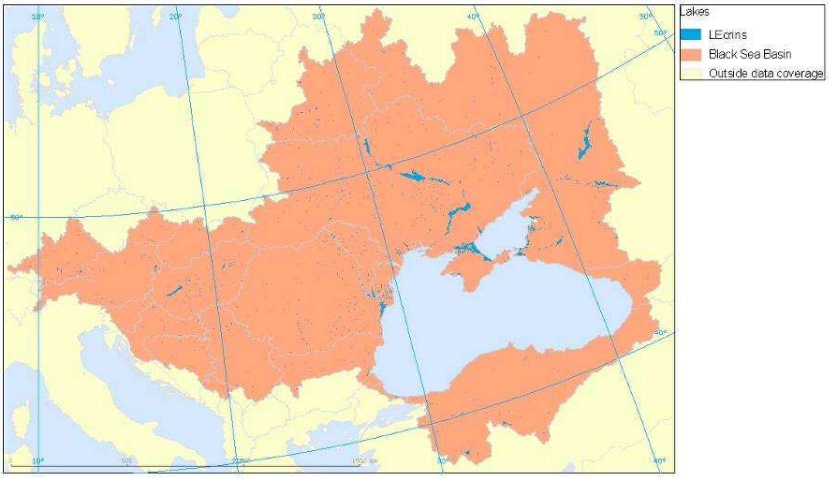

Figure 21: Lakes

Soil quality map - Soil Geographical Database of Euroasia – the soil quality map should be derived from Soil Geographical Database of Euroasia (SGDE) at 1: 1,000,000. This product was developed jointly by the European Commission / Joint Research Centre and European Soil Database in a collaborative project involving all the European Union and neighbourhood countries. The SGDE is a simplified representation of the diversity of the soil coverage representing the main soil types based on the terminology of the FAO legend for the Soil Map of the World at scale 1:5,000,000. The database contains a list of Soil Typological Units (STU) and other attributes that describe the nature and properties of the soils.

The principal classes can be exploited to specify a quality of soil resources in relation to their current use and potential. For example, the soil quality is frequently used for crop specific suitability mapping. In this sense, the European Soil database could be used to assess the quality of the soil for agriculture use (EC/JRC) (Figure 22).

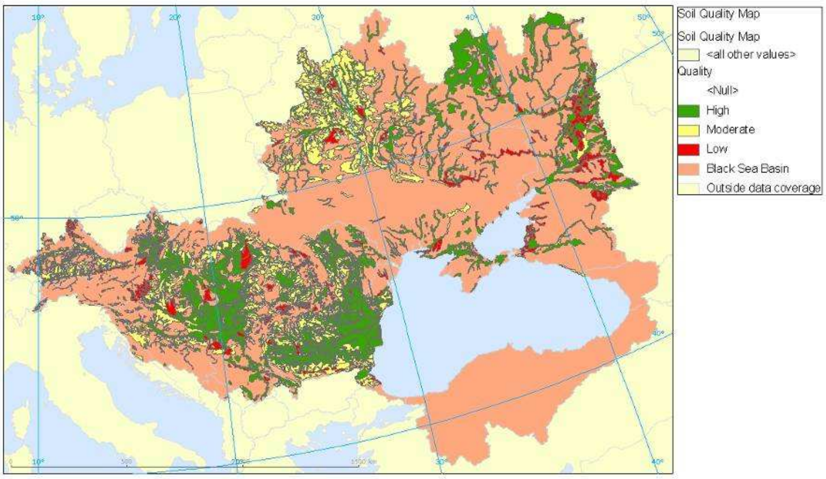

Figure 22: Soil quality map for the Black Sea Basin

Climate data (precipitation and temperature) – WorldClim – the WorldClim is a set of global climate layers (climate grids) with very high resolution (1km^2). The Global Climate data cover the global land areas (except Antarctica). This product was developed by Museum of Vertebrate Zoology from University of California, in collaboration with International Centre for Tropical Agriculture (CIAT) and Rainforest Cooperative Research Centre for Tropical Rainforest Ecology and Management. The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second (approximately 1km) and include variables such as monthly total precipitation, and monthly mean, minimum and maximum temperature.

To interpolate the climate layers, a climate database was used that was compiled by Global Historical Climatology Network (GHCN), FAO, World Meteorological Organization - WMO, the CIAT, R-Hydronet and a various additional databases, the DEM – SRTM and the ANUSPLIN software (Hijmans, R.J. et al, 2005). The temporal coverage is from 1960- 1990 period and in some cases from 1950 – 2000 periods.

Climate factors play an important role in land use changes. In agriculture areas for example, the changes in precipitation could justify the intensification in croplands. In forest areas became even more vulnerable to fires if there are favourable climate conditions that cause extreme drought.

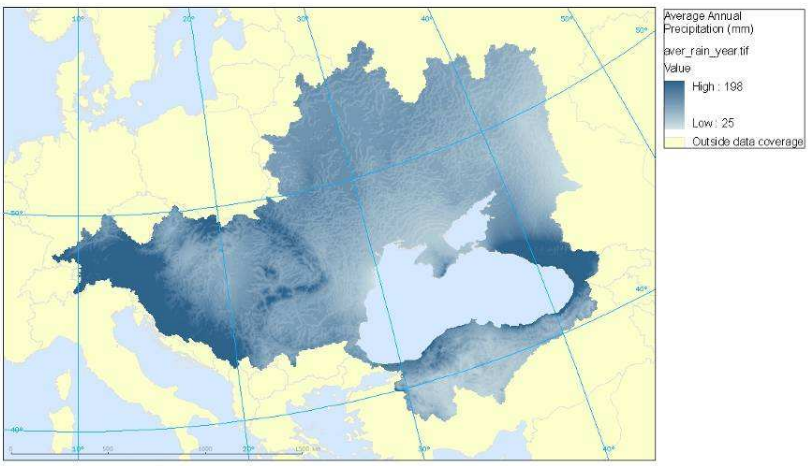

Figure 23: Average annual precipitation, 2000 (mm)

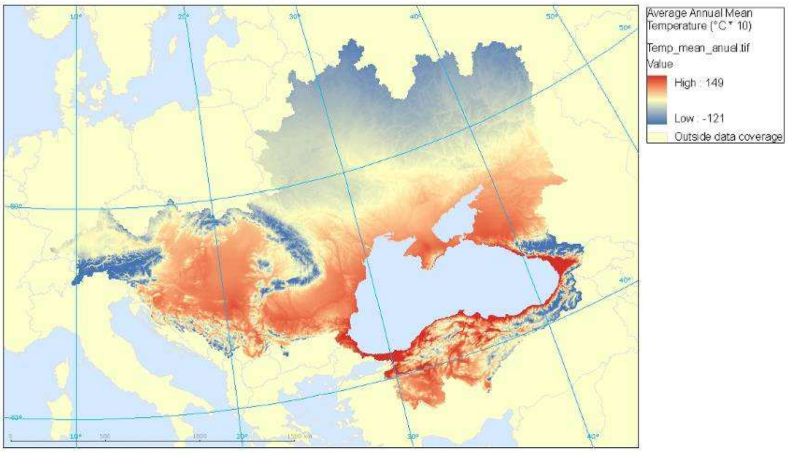

Figure 24: Average annual mean temperature, 2000 (°C * 10)

5.2.3 Zoning and spatial plans

Spatial policies can influence the patterns of land use change in different ways. There are three different types of land use spatial policies:

- Restriction of land use/cover change for example with Natura2000,
- Restriction from specific conversions for example agriculture areas to residential areas,
- Stimulation and discouragement of certain land use, for ex. the intensification of agriculture is a direct result of various measures such as, subsidized inputs and price supports that enable farms to profitably cultivate new crops (McConnel and Keys, 2005 IN Lambin 2006).

Natura2000[11] – The Natura2000 is considered the most important conservation effort implemented in Europe. The aim of Natura2000 Network is to protect and manage vulnerable species and habitats across their natural range within Europe countries, irrespective of national or political boundaries. This spatial policy looks for rationalise environmental conservation measures. The creation of the coherent network "Natura2000" is the result of the measures for the implementation of EU habitats directive 92/43/EEC and Bird Directive 79/409/EEC (Figure 25).

For European countries, the data used should be, the NaturaSite. The NaturaSite is a compilation dataset based on the Naturasite100km feature and merged with 30 meter buffers around NaturesiteLine, NatureSiteMultipoint & NaturaSitePoint at 1:100.000 scale.

[11] Natura2000 oficialweb-page: http://ec.europa.eu/environment/nature/natura2000/index_en.htm

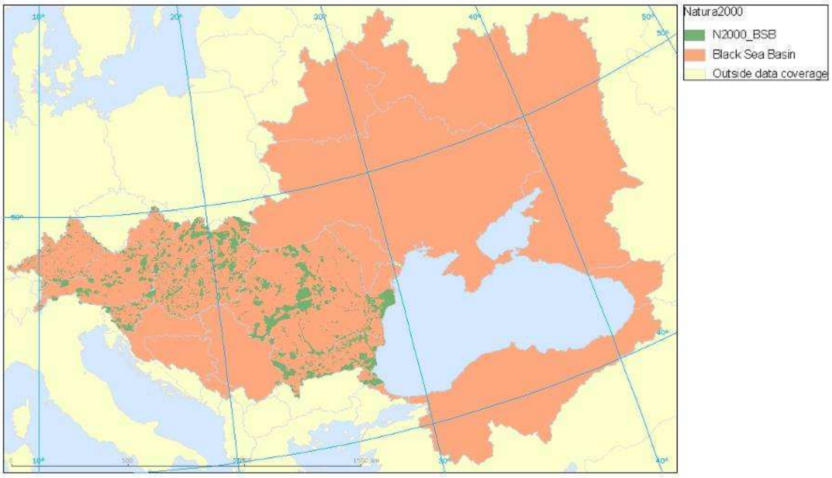

Figure 25: Natura 2000

The European Common Database on Designated Areas – ECDDA was developed by European Environment Agency together with UNEP – World Conservation Monitoring Center. This database aims to manage and harmonized information on marine and terrestrial protected areas. The ECDDA, comprises information reported by countries, including information on location, area and boundaries of all designed sites under national and sub-nation legislation, European community legislation and council of Europe, international conventions, agreements and programs (Figure 26).

The Protected Areas Database includes a spatial layer for national designated protected areas based on their digitised boundaries. The ECDDA spatial data covers European, Russia, Central Asia and Greenland.

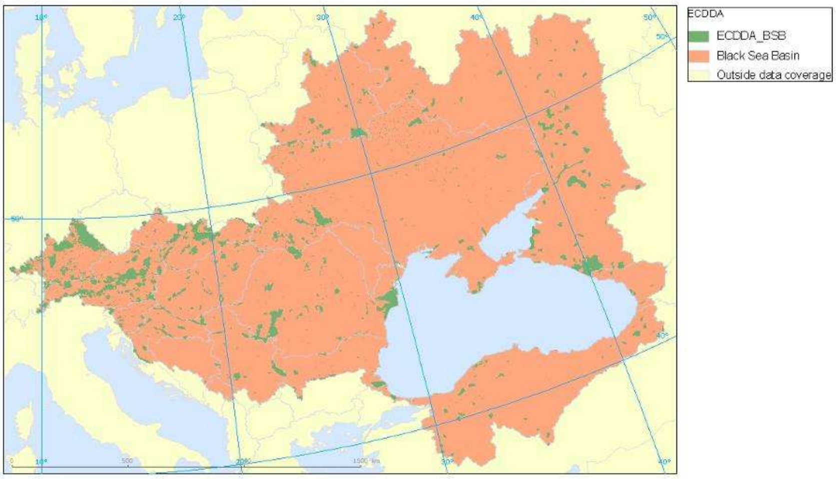

Figure 26: European Common Database on Designated Areas

The ECDDA information and the World Database on Protect Areas (WDPA) had worked together to harmonize the data format, content and timing of dataflow management, quality control procedures, dissemination and access to information, and taking of data licensing or restrictions on datasets provided to ECDDA. Since 2008, the database was release by EEA for public access.

5.2.4 The Infrastructure and Settlements

The transport infrastructure such as roads, railways and settlement infrastructures are important factors determining the spatial location of land use changes. Such data should be used as location measures for namely urban centre proximity, highway proximity, node point proximity.

Regarding the infrastructure data, there are various reference sources. For European countries of Black Sea Basin, the GISCO reference source, offers a complete data set for this purpose.

The GISCO was developed, maintained, updated and distributed by Eurostat/ European Commission. GISCO is a reference database that includes multi-layers covering topographic and thematic layers. The GISCO reference data set provides spatial component of data sets operating at least at five different scale layers 1:25 million, 1:10 million, 1:3 million, 1:1 million, and 1:100 000, of which the 1:1 million.

The *Transport version 2 (2008)* layer contains feature classes representing: railway lines; railway stations; roads; road junctions (major interchanges); level crossings; ferry routes; and customs points at border crossings.

The dataset has been created using Euro Regional Map (ERM) version 2.2 and Euro Global Map (EGM) version 2.1 from EuroGeographics. ERM data is intended for use at map scale 1:250 000 and EGM data at 1:1 000 000, so features may have been generalised for display at these scales. Level crossings and road interchange feature classes are at 1:250K only, but there are both 250K and 1M scale versions (Figure 27).

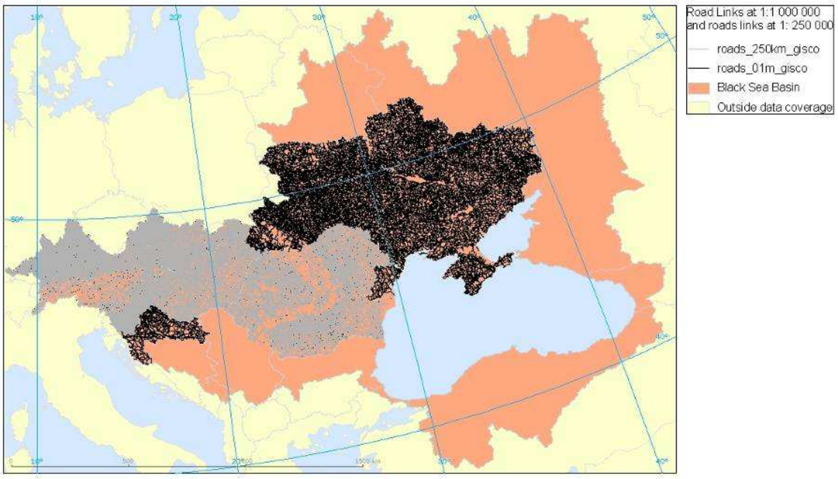

Figure 27: Roads Links (Source: GISCO)

Geographical coverage varies between feature classes. The roads layer at 1: 250 000 cover ten countries of the BSB such as Austria, Czech Republic, Germany, Hungary, Italy, Moldavia, Poland, Romania, Slovenia and Slovakia. Meanwhile the roads links at 1: 1 000 000 cover much more countries. Apart from the countries mentioned previously, this layer includes also roads data for Switzerland, Croatia, Ukraine and Serbia.

The ESRI data base (2008) provides data for infrastructure and settlements. The infrastructure datasets include the Pan-European major roads and secondary roads (scale 1:250 000), railroads and railroad stations (1:100 000) (Figure 30), cities points and populated places (1:100 000) (Figure 29).

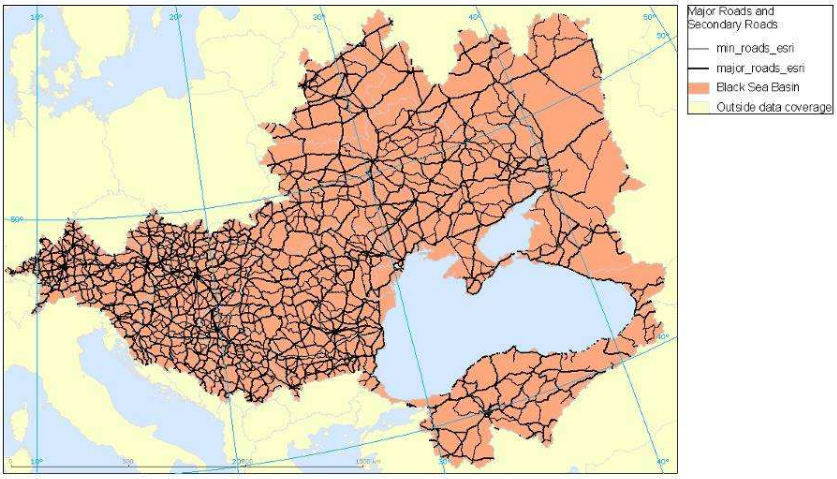

Figure 28: Major Roads and Roads (Source: ESRI)

Although, this data is not as complete as GISCO data base, the geographical coverage of ESRI data base covers all BSB. In this sense, for the neighbourhood countries, it should be most appropriate to get information about infrastructures and settlements from this data, in order to close the data gap in neighbourhood countries.

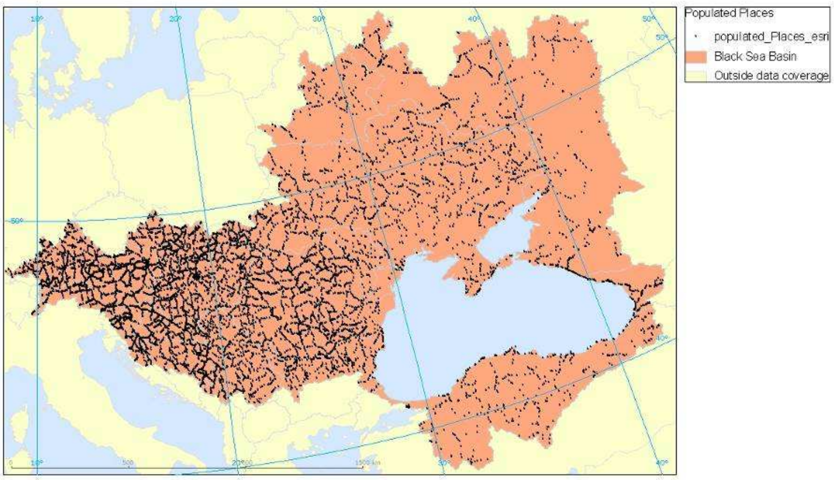

Figure 29: Populated Places (Source: ESRI)

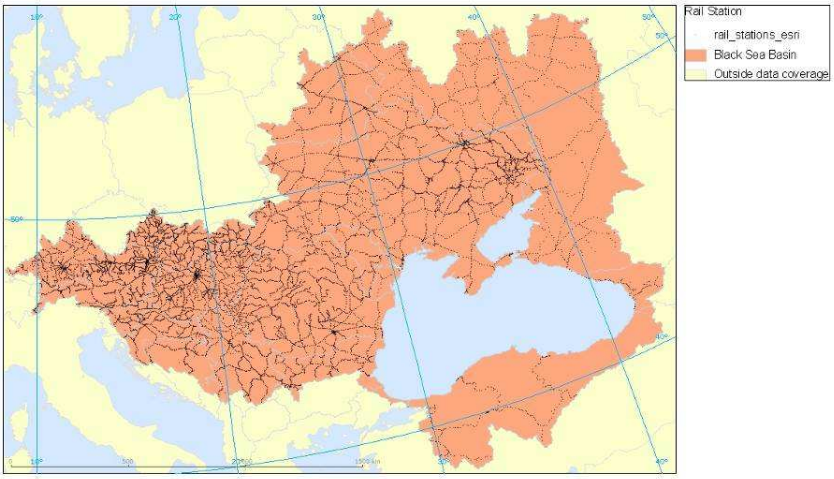

Figure 30: Rail Stations (Source: ESRI)

5.3 Datasets for validation of modelling results

Reference Land cover data on Romanian territory, supplied by DDNI, could be used for validation.

Apart from Corine Land Cover Maps 1990, 2000, 2006 already integrated in the EEA Data base repository, the following images and maps datasets are available.

5.3.1 Semi-natural grasslands of Romania

The data set cover 650,000ha of semi natural grasslands polygons distributed on Romanian territory in 5 bioregions (Alpine, Continental, Pannonic, Pontic and Steppic). Scale of the vector dataset is 1/25000 in the Reference system STERO 70, Projection Double_Stereographic/D_Dealul_Piscului_1970, ellipsoid Krasovski 1940, Datum D_Dealul_Piscului_1970.

Each polygon is mapped at Alliance level, with attached the list of species and additional information on management type, and state of the grassland.

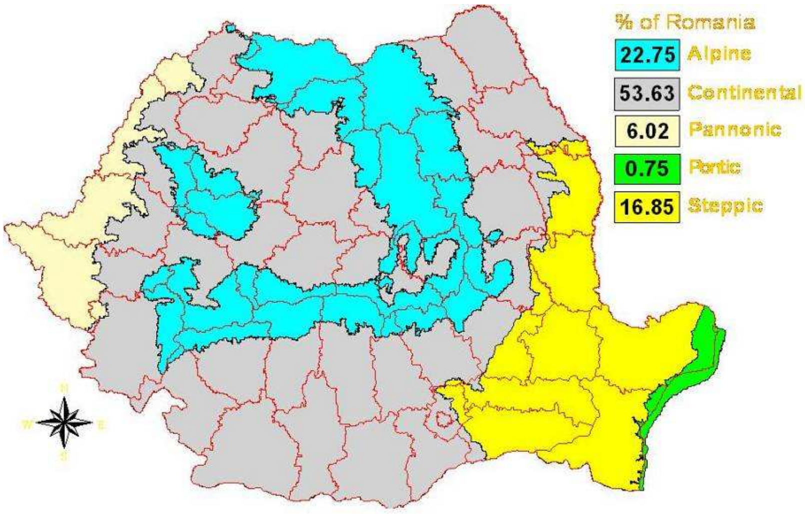

Figure 31: Distribution of the Bioregions on Romanian territory

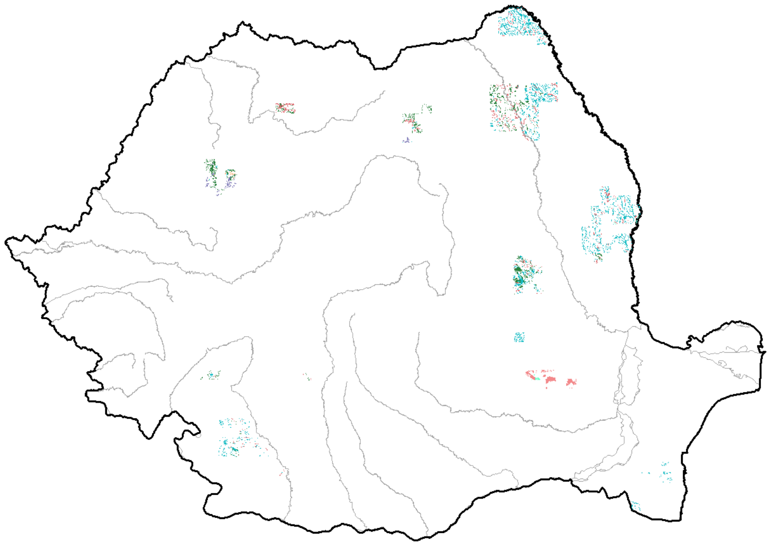

Figure 32: Distribution of Grassland polygons (data base 2010)

5.3.2 Transboundary vegetation map of the Biosphere Reserve "Danube Delta"

The mapped area covers 544,941 ha of which 500,670 ha in the Romanian Danube delta and 43,821 ha in the Ukrainian Danube delta. Scale of the vector dataset is 1/ 25 000 in the Reference system STERO 70, Projection Double_Stereographic/D_Dealul_Piscului_1970, ellipsoid Krasovski 1940, Datum D_Dealul_Piscului_1970. The map show the distribution of 44 vegetation units of marsh, sea shore, river levee and sand dunes land forms of the area. Additionally a report of the vegetation map explain legend units , give synthesis tables of key plant communities groups and species list and make an overview of protection status of plant species.

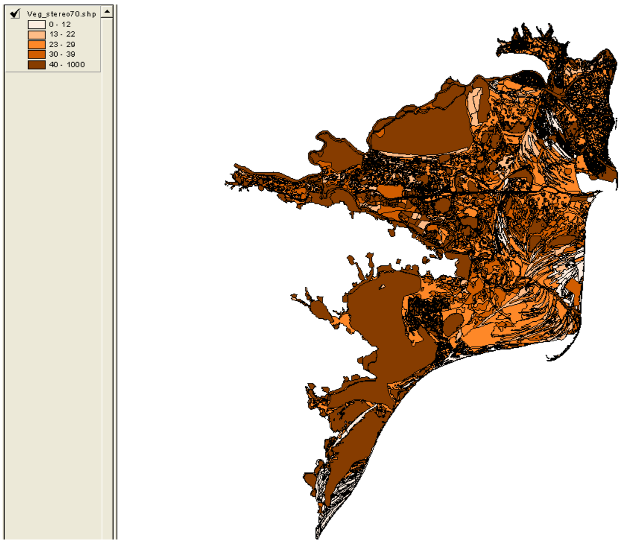

Figure 33: Vegetation map of the Biosphere Reserve " Danube Delta"

5.3.3 Natura 2000 map data base of Romania (2010)

Reference system STERO 70, Projection Double_Stereographic/D_Dealul_Piscului_1970 , ellipsoid Krasovski 1940, Datum D_Dealul_Piscului_1970.

Scale map 1/ 50000 final data base at 1/ 5000 (in process)

5.3.4 High resolution remote sense imagery

Regarding the high resolution remote sense imagery, the following options should be presented the:

Ortho rectified black and white airborne photographs of the Danube Delta (Romanian territory) of the years 1974, 1984, 1990, 1991, 2006 Reference system STERO 70, Projection Double_Stereographic/D_Dealul_Piscului_1970, ellipsoid Krasovski 1940, Datum D_Dealul_Piscului_1970.

- Spot 5, 2,5 m resolution cover whole Romania (2006-2008) Reference system STERO 70, Projection Double_Stereographic/D_Dealul_Piscului_1970 , ellipsoid Krasovski 1940, Datum D_Dealul_Piscului_1970.
- Danube Green corridor LIDAR maps of lower Danube river and airborne images in, Reference system STERO 70, Projection Double_Stereographic/D_Dealul_Piscului_1970, ellipsoid Krasovski 1940, Datum D_Dealul_Piscului_1970.

Remote sensing techniques for mapping Danube delta territory were used since 1980 for testing the potential of Landsat images and later on for production of the vegetation map of the Danube delta (Hanganu J., 1993, 2002). Visual photo interpretation of black & white air photographs and Landsat satellite images was the common method and later on supervised classification of the satellite images combined with airborne videography for calibration (Curtice R. Griffin, 2006). Most recently (Grigoras, Guttler, 2008), the potential of Definiens (eCognition) and ENVI 4.4 software was tested for mapping wetland and terrestrial vegetation and land features on Danube delta territory. Support Vector Machine

(SVM) method was used for "pixel by pixel "classification and segmentation and classification method for object oriented approach. The images processed were aerial photographs, multi spectral images Landsat 7, and Spot 5 and hyper spectral images CHRIS/PROBA.

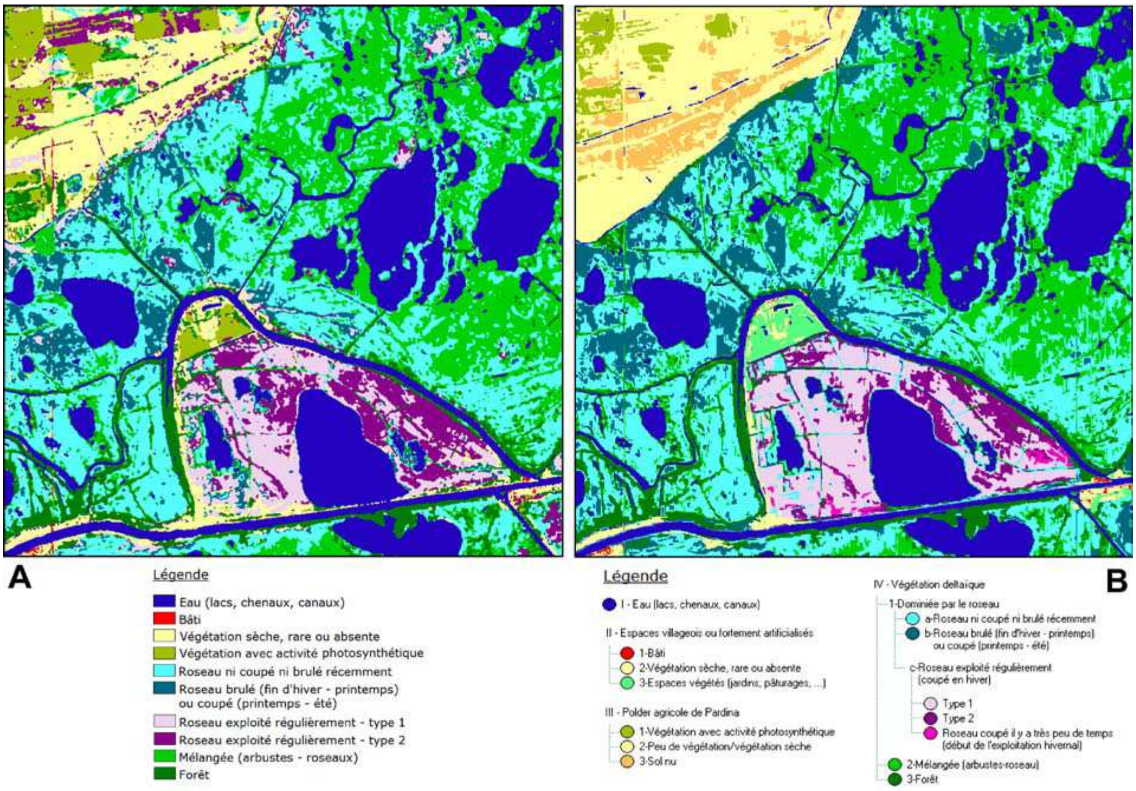

Figure 34: Results of the two methods: A - ''pixel by pixel''; B - ''object oriented'' (Güttler, 2008)

Both methods give good classification results (fig. 1) but the object oriented approach was simpler to use, as the pixel by pixel method requires more effort for image pre-treatment and algorithms for classification.

6 Conclusions and Recommendations

The reviewed state-of-the-art in land use modelling offers ample sources of guidance for construction of spatially explicit scenarios in the Black Sea Basin, and also a well accepted approach, the Integrated assessment of land use systems approach using LUCC models and scenarios, developed with interaction of stakeholders.

The first part of this document presented an extensive overview of land use modelling methods and approaches and available modelling tools. Generally the needs and ambitions to predict land cover have raised very high in the last decade, as clearly demonstrated by the increase of European research initiatives including the reviewed FP7 and EEA studies, most of which aim to provide policy support. These demands have not been well met by convincing modelling tools until now as can be concluded from the reviewed published literature on land use modelling. Present state-of-the-art in land use modelling allows for limited predictive capacity over periods of time spanning at least a couple of decades, especially when considering the multiple and overlapping functions of land in intensively used and cultural landscapes with long history of land tenure. The lack of spatially explicit land cover maps allowing to detect actual trends is one part of the problem; the changing patterns of future land demands and developments is the other.

Taking into account the above outlined research challenges in Land use modelling, it is recommendable to integrate different methodologies, modelling techniques and model inputs for developing the spatially explicit BSB scenarios. The review of modelling tools, developed and/or applied in previous projects reveals also an ample choice of available models. Following the set of criteria for model pre-selection allowed to focus on four ones for detailed overview and comparison. LCM and CA_Markov were tested for certain functionalities on an area defined for model testing (North Bulgaria). The METRONAMICA and the CLUE model functionalities were explored using the tutorial material provided by the owners.

However, final model selection remains an open issue. Despite the fact that the four models can generally fulfil the same application, they differ in terms of specific features applicability, like level of complexity addressed (modelled dimensions), information on model development, optimization of model input processing, price of purchase and functionalities for specific end-user needs, as policy-impact assessment.

Regarding the main land cover data input, using remote sensing products is now greatly facilitated by the available automated or semi-automated methods for mapping geo-referenced land cover with a high spatial accuracy that in addition can frequently be updated. The updates however are less readily acceptable with the same precision in geo-location and discrimination capacity due to the high variation of vegetation conditions and atmospheric influences on the remote sensing images input for automated classification. Following a comparative assessment of the latest global land-cover maps it was deduced that at present, these products (also reported in the EnviroGRIDS deliverable D2.4) are suitable for spatially explicit accounting of main land cover categories but do not allow for temporal changes comparison. Therefore, it is emphasised that there are inherent limitations in using current global land cover datasets, and it would be wise to utilise multiple datasets for comparison.

It was recommended in the literature the use of fuzzy logic and prior knowledge for improved agreement between the datasets, as well as efforts to create a composite ‘‘best-of’’ global land cover dataset which includes all existing products, along with other related datasets, that would be essentially a land cover probability map. The EEA has been using a methodology for creation of probability maps, called CORILIS extracted from the CORINE LC and applied for different land analysis purposes. The statistical sources of land-cover, mainly FAO, national and European ones (as EUROSTAT) can be used for analysing land use change processes in temporal perspective, spanning the last five decades. Combining statistical sources with records on crops and spatial probability maps on agricultural use may allow for downscaling of certain cultivations or land uses of interest.

Main categories of thematic data needed for land use modelling as biophysical and climate datasets, protected areas and transport infrastructure were reviewed and first selection of sources are presented. For optimal use of the available resources, the working team proposed a work flow starting with presentation of the global picture for the Black-Sea Basin using data covering the entire basin and afterwards improve and calibrate the first output using local and regional datasets. The overall working flow for spatially explicit land use scenarios development is structured according to the following steps:

1. Overview of land use models and projects

2. Selection of models to build integrated land use scenarios

3. Definition of the main inputs for the selected model

4. Collection and preparation of the data

5. Calibration and parameterization of the models

6. Results analysis and assessment of land cover changes for the different scenarios in Black Sea Basin.

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Abbreviations and Acronyms

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATEAM	Advanced Terrestrial Ecosystem Analysis and Modelling
AVHRR	Advanced Very High Resolution Radiometer
ANN	Artificial Neuronal Network
BSB	Black Sea Basin
CAP	Common Agricultural Policy
CCM	Catchment Characterisation and Modelling
CLUE	Conversion of Land Use and its Effects
CLC	Corine Land Cover
DEM	Digital Elevation Model
DG	Directorate General
DPSIR	Driver, Pressure, State, Impact and Response
RIVM	Dutch National Institute for Public Health and the Environment
ESRI	Environmental Systems Research Institute
EPA	Environmental Protection Agency
ECRINS	European Catchment and Rivers Network System
ECDDA	European Common Database on Designated Areas
EEA	European Environment Agency
ERM	Euro Regional Map
EGM	Euro Global Map
EU	European Union
FAO	Food an Agriculture Organization of the United Nations
FoPIA	Framework for Participatory Impact Assessment
FP	Framework Programme
GISCO	Geographic Information System of the European Commission
GHCN	Global Historical Climatology Network
GLC2000	Global Land Cover 2000
GLCC	Global Land Cover Characterization Data Base
GTAP	Global Trade Analysis Project
FÖMI	Institute of Geodesy, Cartography and Remote Sensing
IUNG	Institute of Soil Science and Plant Cultivation

IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
CIAT	International Centre for Tropical Agriculture
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme
JRC	Joint Research Centre
LARU	Land Analytical and reporting units
LCM	Land Change Modeler
LEAC	Land Cover Accounts
LCCS	Land Cover Classification System
LCF	Land Cover Flow
LUCC	Land Use Cover Change
MERIS	MEdium Resolution Imaging Spectrometer
MEA	Millennium Ecosystem Assessment
MODIS	Moderate Resolution Imaging Spectroradiometer
MCE	Multi-criteria Evaluation
NOAA	National Oceanic and Atmospheric Admininstration
NDVI	Normalized Difference Vegetation Index
OLAP	On-line Analytical Processing
OECD	Organization for Economic Co-operation and Development
PELCOM	Pan-European Land Use and Land Cover Monitoring
PLUREL	Peri-Urban Land Use Relationships
PSS	Policy Support System
PRELUDE	PRospective Envrionmental analysis of Land Use Development in Europe
RIKS	Research Institute for Knowledge Systems
SGDE	Soil Geographical Database of Euroasia
STU	Soil Typological Units
SRES	Special Report on Emissions Scenarios
SIAT	Sustainability Impact Assessment Tool
USGS	U.S. Geological Survey
UNEP	United Nations Environment Programme
UMD	University of Maryland
UNL	University of Nebraska-Lincoln
WIST	Warehouse Inventory Search Tool

WDPA	World Database on Protect Areas
WMO	World Meteorological Organization - WMO

Terminology

The terms and definitions used in this document are according with the terminologies published by EEA – Environmental Terminology and Discovery Service (ETDS)[12].

Driving Force	In the EEA indicator system, indicators for driving forces describe the social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns. Primary driving forces are population growth and developments in the needs and activities of individuals. These primary driving forces provoke changes in the overall levels of production and consumption. Through these changes in production and consumption, the driving forces exert pressure on the environment. [definition source: EEA. 1999. Environmental indicators.: Typology and overview. Technical report No 25.]
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. [definition source: The Convention on Biological Diversity.]
Indicator	Something that provides an indication especially of trends. (Source: CED)
Land Cover	Land cover corresponds to a (bio)physical description of the earth's surface. It is that which overlays or currently covers the ground. This description enables various biophysical categories to be distinguished - basically, areas of vegetation (trees, bushes, fields, lawns), bare soil, hard surfaces (rocks, buildings) and wet areas and bodies of water (watercourses, wetlands). [definition source: European Commission.]
Land Use	Land use corresponds to the socio-economic description (functional dimension) of areas: areas used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes, etc. Links with land cover are possible; it may be possible to infer land use from land cover and conversely. But situations are often complicated and the link is not so evident. Contrary to land cover, land use is difficult to 'observe'. For example, it is often difficult to decide if grasslands are used or not for agricultural purposes. Distinctions between land use and land cover and their definition have impacts on the development of classification systems, data collection and information systems in general. [definition source: EEA multilingual environmental glossary]
Model	1) A representation, usually on a smaller scale, of a device, structure, etc. 2) A quantitative or mathematical representation or computer simulation which attempts to describe the characteristics or relationships of physical events. (Source: CED / LEE)
Parameter	1) A quantity in an equation which must be specified beside the independent variables to obtain the solution for the dependent variables. 2) A quantity which is constant under a given set of conditions, but may be different under other conditions. (Source: LEE / MGH)

[12] EEA Glossary web-page: URL http://glossary.eea.europa.eu/terminology/list_html?letter=A

Scenario	A plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g. rate of technology changes, prices). Note that scenarios are neither predictions nor forecast. [definition source: Intergovernmental Panel on Climate Change.]
Validation - Spatial Models	Demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model (Rykiel, 1996 In Lambin, et al. 2006)

Annex I: Resume of European Projects

	PRELUDE	EURURALIS	SENSOR - SIAT	SCENAR2020	FORESCENE	ATEAM
Project and Institution	PRospective Envrionmental analysis of Land Use Development in Europe (European Environment Agency)	EURURALIS Wageningen University and Research Centre (2004)	Sustainability Impact Assessment Tool (EU FP6 Integrated Project, 2004)	SCENAR 2020 – Scenario Study on Agriculture and Rural World (EC, 2007)	FORESCENE Forecasting Framework and Scenarios to Support the EU Sustainable Development Strategy (EU FP6 Integrated Project, 2006)	ATEAM – Advanced Ter Ecosystem Analysis and Modellir FP5, 2001)
Themes analysed	Landscape changes (Urban, Grassland, Cropland. Cropland for Biofuel, Abandoned Land)	Land use changes; Agriculture Employment; Self-sufficiency; Animal disease; Nitrogen emission and deposition; Soil degradation and Stalinisation; Biodiversity; Carbon sequestration; Biofuel cropland; Agriculture land; Real farm income	Land use sectors: agriculture, forestry, tourism, nature protection, transport and energy infrastructure.	The rural demographic patterns; The agricultural technology; The agricultural markets; The natural and social constraints on land use that are likely to exist in 2020	Agriculture; land use; infrastructures; Industry and Economy	Displays the vulnerability of si sectors: agriculture, forestry, storage and energy, water biodiversity.
Scenarios	- Great Escape - Evolved Society - Clustered Networks - Lettuce Surprise U - Big Crisis	- A1 Global Economy - A2 Continental Markets - B1 Global Co-operation - B2 Regional Communities	- Low growth - Medium - High_growth	- Reference scenario ('baseline') - Regionalisation scenario - Librealisation scenario	- Baseline scenarios - Commitment to change - Muddling through - Failing to deliver	4 SRES scenarios - A1f - A2 - B1 - B2

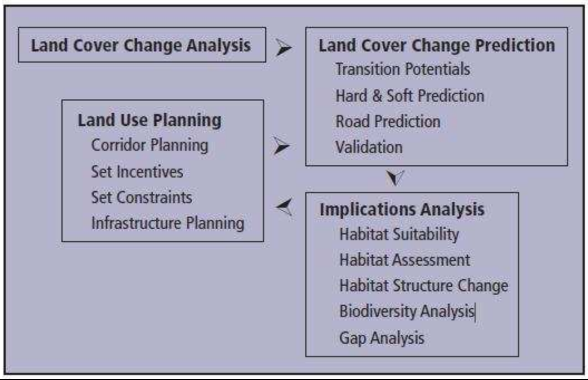
Stakeholders participation on scenarios	Participation of diversified panel composed by thirty specialists, involving researchers, representative groups of interest and general public with different interest and perspectives.	Qualitative analysis and expert judgment.	Was developed a Framework for Participatory Impact Assessment – FoPIA (Morris et al. 2008), involves national, regional and local stakeholders in assessment of land use policy impacts	Qualitative analysis and expert judgment	DG's, stakeholders and experts in order to integrate knowledge on various environmental problems and priority policy fields and define essentials for integrated sustainability scenarios	The stakeholders input help to q regional adaptive capacity. stakeholders include natural re managers, planners and decision-m both within the private and public s
Driving forces identified	20 driving forces grouped into five categories: - Environmental Concerns - Solidarity & Equity - Governance & Intervention - Agriculture Optimisation - Technology & Innovation	Various drivers are study: - Demographic developments - Changes in welfare - Geopolitical Change - Consumer concern - Technological progress - Global change	Driving forces are: - Demographic changes within in Europe - Rate in participation force - Growth of world demand - The price of petroleum on the world market - Research and development	Exogenous drivers: Demography; Macro-economic growth; World Agriculture markets; Consumer (food) preferences; Quality if life and social well-being; Human and animal health concerns; Agri-technology; Environmental Trends (Impact on agriculture); Endogenous drivers: Trade and Agriculture policy; Environmental policy; Enlargement; WTO and other international agreements	-Economic and Structure - Production Patterns - Consumption patterns - Demography - Institutions	Cross-cutting drivers at the Eu Scale: - Economy - population - technology - institutions and government - rural development - Recreation and tourism - Spatial planning - EU enlargement
Horizonte time	2035	2030	2025	2020	2025	2080

Modelling approach	Europe level: -Louvain-la Neuve LUC Model Regional Level: -Metronamica	Global economic model: – GTAP/LEITAP Environmental Model: – IMAGE Allocation Model: - CLUE-s	Macro economic model: NEMESIS Sector model: - Agriculture CAPRI - Forestry – EFISCEN - Urban - SICK - Tourism - B&B - Transport - TIM for Allocation model: - Dyna -CLUE	Global Economic model: LEITAP Environmental model: IMAGE Sector model: - Agriculture: ESIM and CAPRI Allocation model: - CLUE-s	Bayesian Modelling	Sector model: - Agriculture: Land use scenario; SUNDIAL, ROTH IMAGE (Biofuel demand) - Forestry: GOTILWA+ and EFIS - Carbon Storage: (biogeochemistry) - Water: Mac-pdm - Biodiversity and Nature Conser Statistical niche modelling - Mountains RHESsys (mountiain

Annex II. Template of the key characteristics of land use models

Model dimension	
Input (Key drivers)	Which are the key driving forces, input data or parameters used by the model?
Output (Key Indicators)	Which are the key indicators/ primary output variables computed by the model?
Geographical coverage	What spatial coverage / geographical extent does the model operate on and provide output for? And at what spatial resolution
Temporal coverage	For what time horizon does the model deliver results? And for what time steps?
Model approach	What kind of techniques use to allocate de land use?
Model structure	A diagram that summarizes the main model structure
Information on model development	
Model developers/owners	Who as developed the model? And who sponsors its development and who owns it?
Target group /users	For which audience has the model been developed? Who has used the model and its outputs? Has the model been used for policy purposes?
Uncertainty analysis	Is the model suitable for undertaking uncertainly analysis (such as Monte Carlo simulations, variants, stress testing for boundary conditions)?
Key reference	What is the key (peer-reviewed) publication that describes the model?
Information on use of model	
Level of integration	What level of integration across environmental themes does the model allow are feedbacks addressed, e.g. between response options and drivers?
Link to other models	Has the model been linked to other models for integrated assessment? Examples.
Ease to use interface	Is the model easy to use for non-developers? Is the model free to access? What restrictions apply? Are the results publicly available? Is there a user manual?
Use in participative processes	Has the model or a simplified version of the model been used in interactive settings or participative processes. Examples.
Cost	

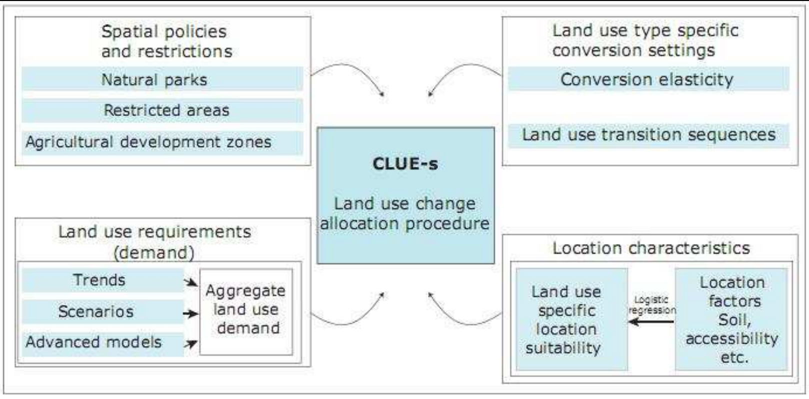
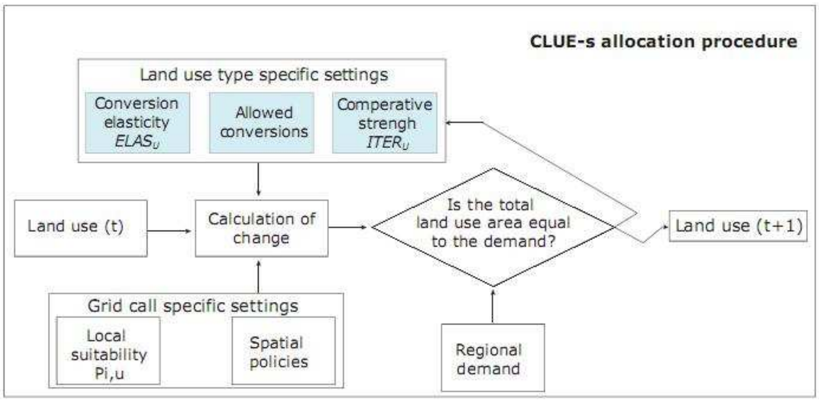
Annex III: Land Change Modeler main characteristics

LAND CHANGE MODELER (Eastman, 2006)	
Model dimension	
Input (Key drivers)	- Land use maps - Biophysical and socio-cultural factors: population, economic activity, topography, rivers and lakes, roads and railways and climate data (annual temp. and precipitation). - Infrastructures (roads) - Zoning plans
Output (Key Indicators)	- Land use prediction - Vulnerability to change for the selected set of transitions.
Geographical coverage	- Country (e.g. Bolivia, Madagascar, Mexico) - Resolution between : 100m to 1km
Temporal coverage	- User specified (e.g. Madagascar 30 years)
Model tecnhiques	- Transition model: Multi layer perception or Logistic Regression - Land change allocation model: Markov Chain
Model structure	
Information on model development	
Model developers/owners	Clark Labs, Clark University, the USA
Target group /users	The Land Change Modeler have been applied in research institutes, universities and government.
Calibration	The calibration comes form the land use patterns based on historic data.
Validation	Based on historic land use maps.
Uncertainty analysis	Clark labs have different ways to manage the uncertainty including Monte Carlo analysis, Dempster-Shafer evidence aggregation procedure in GIS and soft reclassification procedure (PCLASS) that allows one to map the probability of a location being above or below a threshold (such as sea level rise)
Key reference	Clark Labs, 2009, *Land Change Modeler for Ecological Sustainability*: [electronic version: http://www.clarklabs.org/applications/upload/Land-Change-Modeler-IDRISI-Focus-Paper.pdf]
Information on use of model	
Level of integration	The level of integration is high. LCM is an integrated vertical application designed to analyse and predict future land cover changes and the effects of land cover change on biodiversity and planning
Ease to use interface	The LCM provides a simple GUI interface, sequentially organized around the major task: land change analysis, Transition Potentials, Change prediction, Implications and Planning.
Cost	Aproxi. 500 Euros[1]

Annex IV: CA_Markov main characteristics

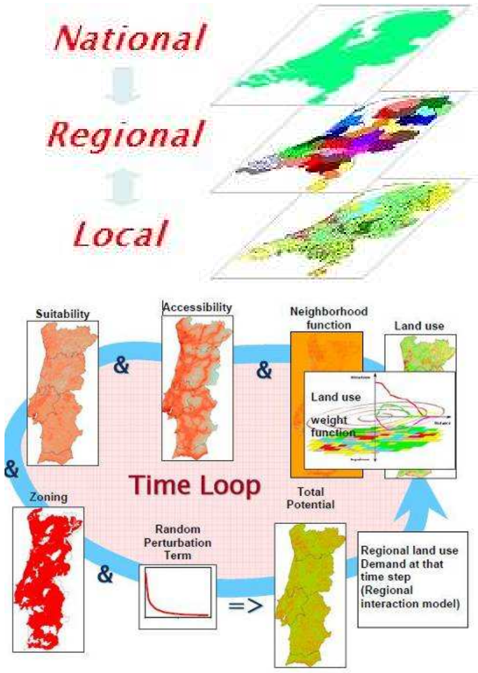
CA_Markov	
Model dimension	
Input (Key drivers)	- Land cover maps - According to the criteria stipulated by the user for suitability maps for each transition: proximity to roads, to water bodies, protected lands, existing land cover, slope, distance to urban center, etc.
Output (Key Indicators)	- Land use prediction (Predict any transition among any number of categories)
Geographical coverage	- For example: - Sintra and Cascais (Portugal) - Terrebonne Basin, Louisiana (U.S.A.)
Temporal coverage	- User specified (e.g. Sintra and Cascais till 2025)
Model approach	- Transition modeled: Multi criteria evaluation or Logistic Regression - Land change allocation: Cellular Automata and Markov Chain
Model structure	….
Information on model development	
Model developers/owners	Clark Labs, Clark University, the USA
Calibration	CA_Markov is typically calibrated with reference maps form two points in time. T0 and T1.
Validation	Is the process of comparing the models prediction results for time t2 to a reference map of time t2.
Target group /users	The CA_Markov has been applied in research institutes and universities.
Uncertainty analysis	Clark labs have different ways to manage the uncertainty including Monte Carlo analysis, Dempster-Shafer evidence aggregation procedure in GIS and soft reclassification procedure (PCLASS) that allows one to map the probability of a location being above or below a threshold (such as sea level rise)
Key reference	Pontius, Gil R. and Malanson, Jeffrey(2005) 'Comparison of the structure and accuracy of two land change models', International Journal of Geographical Information Science, 19: 2, 243 — 265
Information on use of model	
Level of integration	
Ease to use interface	The CA_Markov provides a GUI interface, that requires minimum expertise on land use system to set-up the model (suitability maps for each transition, Markov transition matrix and number of Cellular Automata interactions).
Use in participative processes	
Cost	Aproxi. 500 Euros[1]

Annex V. CLUE-S model main characteristics

CLUE-s (Verburg, et al 2004)	
Model dimension	
Input (Key drivers)	Possible data: - specific crops (sown area and yields) - land cover image - animal husbandry (e.g. number of pigs) - demographic data (rural and urban population) - socio-economic data (e.g. income or GDP) - management data (e.g. irrigated area, cropping index - geographic data (e.g. distance form city) - Biophysical data (e.g. DEM, Relief, Geology)
Output (Key Indicators)	Land use change scenarios
Geographical coverage	- Coverage: Eu:27 (SENSOR, SCENAR2020, EURUALIS) - Resolution:1 km by 1km grid
Temporal coverage	- 20 to 40 years
Model tecnhiques	- Statistical regression - Cellular automata
Model structure	 
Information on model development	
Target group /users	The CLUE-s have been applied in research institutes, universities and government institutions.
Calibration	The calibration comes form the land use patterns based on historic data.
Validation	Based on historic land use maps.

Uncertainty analysis	In some case studies it was applied the Monte Carlo method to assess the impact of parameter uncertainty of the CLUE-s- model
Key reference	Verburg, P.H., Soepboer, W., Limpiada, R., Espaldon, M.V.O., Sharifa, M.A., Veldkamp, A. 2002 Modelling the spatial dynamics of regional land use: The CLUE-S model. Environmental Management, 30, 391-405.
Information on use of model	
Level of integration	
Ease to use interface	Only for the Dyna-CLUE version of the model a user-interface is available and regularly updated. The CLUE or CLUE-s full version with technical support is only available for collaborative projects.
Use in participative processes	
Cost	CLUE is a freewhare software available for use in scientific studies. Implementation of the software in commercial software is not allowed.

Annex VI: METRONAMICA model main characteristics

METRONAMICA	
Model dimension	
Input (Key drivers)	- Land cover - Infrastructure - Biophysical factors - Demographic data (census data: population and jobs plus transport network) - Zonning Plans
Output (Key Indicators)	Land use change scenarios based on alternative policy option
Geographical coverage	Has been applied to a large number of cities, regions and countries worldwide
Temporal coverage	50 years in the future
Model tecnhiques	- Cellular automata - Statistical regression
Model structure	
Information on model development	
Target group /users	The METRONAMICA is used by local and regional governs and research institutes.
Calibration	The calibration procedures is based on historic data and aims to produce a set of transition rules that generates a model output with the best possible goodness or fit between the simulated map and the actual available map.
Validation	The validation process include of the degree of coincidence between the two land use maps using a cell-by-cell comparison method and associated two statistics *kappa* and *fuzzy kappa* (*fuzzy-k*)
Uncertainty analysis	The METRONAMICA model applied the Monte Carlo method to assess the impact of parameter uncertainty of the model.
Key reference	Nijs, T. de, Niet, R. De & Crommentuijn, L. (2004). Constructing land-use maps of

	the Netherlands in 2030. Journal of Environmental Management, 72, 35-42. Van Delden, H., Escudero, J.C., Uljee, I., Engelen, G., 2005. METRONAMICA: A dynamic spatial land use model applied to Vitoria-Gasteiz. Virtual Seminar of the Miles Porject. Centro de Estudios Ambientales, Vitoria Gasteiz
Information on use of model	
Level of integration	The METRONAMICA provides a strong integrative, interactive and highly dynamic The output form the regional model is used as a input to the local model.
Link to other models	Depending on the exact version, the METRONAMICA incorporates several simulation models that are coupled using the GEONAMICA software environment: a local dynamic land use interaction model, a regional interaction model, transport model, demographic model and macro-economic model. The GEONAMICA[1] modelling framework, provides a generic structure for the models that allows them to be integrated more easily while enabling complex dynamic models to be executed efficiently (Hurkens, et al. 2008)[1].
Use in participative processes	The PRELUDE-EEA project for example, used the METRONAMICA as a support of policy making. The process involves 25 stakeholders representing a broad range of European institutes, governmental and environmental organizations, worked together with expert support teams for the development of the stakeholders process, the European and the Regional quantification of the scenarios and modelling.
Ease to use interface	METRONAMCA provides a easy-to-use interface for planers and policy makers.
Cost	24, 900 euros - Metronamica license - Three 3-day training sessions

Annex VII. Hungarian reference data on approved land cover for 2000

CLC code	name	Approved, 2000 Area, ha	%
111	Continuous urban fabric	3493.0	0.0
112	Discontinuous urban fabric	287804.0	3.1
11	Urban fabric	291297.0	3.1
121	Industrial or commercial units	108926.0	1.2
122	Road and rail network and associated land	44800.0	0.5
123	Port areas	595.0	0.0
124	Airports	9097.0	0.1
12	Industrial, commercial and transport units	163418.0	1.8
13	Mine, dump and construction sites	20748.0	0.2
14	Artificial non-agricultural vegetated areas	40249.0	0.4
1.	Artificial surfaces	515712.0	5.5
21	Arable land	4499800.0	48.4
22	Permanent crops	201300.0	2.2
23	Pastures	713900.0	7.7
24	Heterogeneous agricultural areas	395589.0	4.3
2.	Agricultural areas	5810589.0	62.5
312	Coniferous forest	203374.0	2.2
311	Broad-leaved forest	1452873.0	15.6
313	Mixed forest	80253.0	0.9
31	Forests	1736500.0	18.7
321	Natural grassland	593549.0	6.4
324	Transitional woodland/shrub	294097.0	3.2
32	Shrub and/or herbaceous vegetation association	887646.0	9.5
33	Open spaces with little or no vegetation	9662.0	0.1
3.	Forests and semi-natural areas	2633808.0	28.3
411	Inland marshes	116183.0	1.2
412	Peat bogs	11311.0	0.1
4.	Wetlands	127494.0	1.4
511	Water courses	76738.0	0.8
	Fish-pond	32000.0	0.3
	Other water-bodies	104768.0	1.1
512	Water bodies	136768.0	1.5
5.	Inland waters	213506.0	2.3
	TOTAL	9301109.0	100.0

Annex VIII. Definition of land cover flows

LCF1 Urban land management: Internal transformation of urban areas

LCF11 Urban development/infilling: Conversion from discontinuous urban fabric, green urban areas and sport and leisure facilities to dense urban fabric, economic areas and infrastructures

LCF12 Recycling of developed urban land: Internal conversions between residential and/or non-residential land cover types. Construction of urban greenfields is not considered here but as LCF11

LCF13 Development of green urban areas: Extension of green urban areas over developed land as well as, in the periphery of cities, over other types of land uses

LCF2 Urban residential sprawl: Land uptake by residential buildings altogether with associated services and urban infrastructure (classified in CLC111 and 112) from non-urban land (extension over sea may happen)

LCF21 Urban dense residential sprawl: Land uptake by continuous urban fabric (CLC111) from non-urban land
LCF22 Urban diffuse residential sprawl: Land uptake by discontinuous urban fabric (CLC112) from non-urban land

LCF3 Sprawl of economic sites and infrastructures: Land uptake by new economic sites and infrastructures (including sport and leisure facilities) from non-urban land (extension over sea may happen)

LCF31 Sprawl of industrial and commercial sites: Non-urban land uptake by new industrial and commercial sites

LCF32 Sprawl of transport networks: Non-urban land uptake by new transport networks (note that linear features narrower than 100 m are not monitored by CLC)

LCF33 Sprawl of harbours: Development of harbours over non-urban land and sea

LCF34 Sprawl of airports: Development of airports over non-urban land and sea

LCF35 Sprawl of mines and quarrying areas: Non-urban land uptake by mines and quarries

LCF36 Sprawl of dump sites: Non-urban land uptake by waste dump sites

LCF37 Construction: Extension over non-urban land of areas under construction during the period (note: covers mainly construction of economic sites and infrastructures)

LCF38 Sprawl of sport and leisure facilities: Conversion from developed as well as non-urban land to sport and leisure facilities

LCF4 Agriculture internal conversions: Conversion between farming types. Rotation between annual crops is not monitored by CLC

LCF41 Extension of set aside fallow land and pasture: Conversion from crop land to grassland as an agricultural rotation or for cattle husbandry

LCF411 Uniform extension of set aside fallow land and pasture: Large parcels conversion from crop land to grassland

LCF412 Diffuse extension of set aside fallow land and pasture: Conversion from crop land to complex cultivation patterns (with grassland) and from mixed agriculture to large pasture parcels

LCF42 Internal conversions between annual crops: Conversions between irrigated and non-irrigated agriculture

LCF421 Conversion from arable land to permanent irrigation perimeters: Extension of permanent irrigation (incl. rice fields) over arable land

LCF422 Other internal conversions of arable land: Other conversions between arable land and irrigated perimeters, incl. rice fields

LCF43 Internal conversions between permanent crops: Conversions between vineyards, orchards and/or olive groves

LCF431 Conversion from olives groves to vineyards and orchards: Conversion from olives groves to vineyards and orchards

LCF432 Conversion from vineyards and orchards to olive groves: Conversion from vineyards and orchards to olive groves

LCF433 Other conversions between vineyards and orchards: Other conversions between vineyards and orchards

LCF44 Conversion from permanent crops to arable land: Conversion from vineyards, orchards and olive groves to irrigated and/or non-irrigated arable land

LCF441 Conversion from permanent crops to permanent irrigation perimeters: Conversion from permanent crops (incl. when associated with arable land — CLC241) to permanent (large) irrigation perimeters and rice fields

LCF442 Conversion from vineyards and orchards to non-irrigated arable land: Conversion from vineyards and orchards to non-irrigated arable land and from associations of annual and permanent crops to uniform arable land

LCF443 Conversion from olive groves to non-irrigated arable land: Conversion from olive groves to non-irrigated arable land, incl. conversions to associations of annual and permanent crops (CLC241) and of crops and pasture (CLC242)

LCF444 Diffuse conversion from permanent crops to arable land: Conversion from vineyards and orchards to associations of annual and permanent crops (CLC241) and of crops and pasture (CLC242: complex cultivation patterns)

LCF45 Conversion from arable land to permanent crops: Plantation of vineyards, orchards and olive groves on arable land

LCF451 Conversion from arable land to vineyards and orchards: Plantation of vineyards, orchards on arable land

LCF452 Conversion from arable land to olive groves: Plantation of olive groves on arable land

LCF453 Diffuse conversion from arable land to permanent crops: Conversion from uniform arable land to associations of permanent crops and annual crops (CLC241)

LCF46 Conversion from pasture to arable and permanent crops: Conversion from pasture to arable and permanent crops

LCF461 Conversion from pasture to permanent irrigation perimeters: Conversion of uniform pasture areas to permanent irrigation perimeters

LCF462 Intensive conversion from pasture to non-irrigated arable land and permanent crops: Conversion of uniform pasture areas to non-irrigated annual and permanent crops

LCF463 Diffuse conversion from pasture to arable and permanent crops: Conversion from complex cultivation patterns including pasture (CLC242) to uniform arable land and permanent crops as well as to associations of the last two (CLC241) and conversion of uniform pasture (CLC231) to complex cultivation patterns

LCF47 Extension of agro-forestry: Conversion of cultivated land and open pasture to agro-forestry systems such as dehesas and montados (note: conversion from 243 to 244, where natural vegetation is important, is recorded under LCF522)

LCF48 Other conversions from agriculture mosaics to arable land and permanent crops: This land cover class is used only when changes are detected from a Corine land cover matrix combing classification of level2 for the initial year and level 3 for the final year. Agriculture mosaic classes being grouped in CLC24 only, it is not possible to differentiate the processes according to the type of land consumed. It includes in particular the sub-class LCF523, conversions from agriculture-nature mosaics to continuous agriculture, not isolated in this case

LCF481 Other conversions from agriculture mosaics to permanent crops: Used for CLC level 2 x level 3 only. It includes conversion of agriculture-nature mosaics to arable land (see LCF48)

LCF482 Other conversions from agriculture mosaics to arable land (including conversion of agriculture-nature mosaics to permanent crops). Used for CLC level 2 x level 3 only. It includes conversion of agriculture-nature mosaics to arable land (see LCF48)

LCF5 Conversion from forested and natural land to agriculture: Extension of agriculture land use

LCF51 Conversion from forest to agriculture: Deforestation for agriculture purpose, including agricultural conversion of transitional woodland shrub

LCF511 Intensive conversion from forest to agriculture: Deforestation, including agricultural conversion of transitional woodland shrub, for cultivation of annual and permanent crops (incl. in association, CLC241)

LCF512 Diffuse conversion from forest to agriculture: Conversion from uniform forest to complex cultivation patterns, mosaic agricultural landscape and agro-forestry. Due to possible uncertainties in monitoring extension of pasture vs. recent felling, conversion from forests to pasture land (CLC231) is recorded here

LCF52 Conversion from semi-natural land to agriculture: Conversion from dry semi-natural land (except CLC324, grouped with forests) to agriculture

LCF521 Intensive conversion from semi-natural land to agriculture: Conversion from dry semi-natural land (except CLC324, grouped with forests) to annual crops, permanent crops and their association

LCF522 Diffuse conversion from semi-natural land to agriculture: Conversion from dry semi-natural land (except CLC324, grouped with forests) to pasture and mixed agriculture with pasture

LCF523 Conversions from agriculture-nature mosaics to continuous agriculture: Conversion from CLC243, where natural areas are distinctive feature of the land systems to continuous agriculture. This is an over-estimation from an agriculture perspective but is justified in terms of analysis of ecological potentials of complex land systems

LCF53 Conversion from wetlands to agriculture: Conversion of wetlands to any type of farmland (CLC2)

LCF54 Conversion from developed areas to agriculture: Conversion of urban land to any type of farmland (CLC2)

LCF6 Withdrawal of farming: Farmland abandonment and other conversions from agriculture activity in favour of forests or natural land

LCF61 Withdrawal of farming with woodland creation: Forest and woodland creation (incl. transitional woodland shrub) from all CLC agriculture types. Withdrawal of farming with woodland creation is a broader concept than farmland abandonment with woodland creation, which results more from decline of agriculture than afforestation programmes. Additional information is necessary to identify an abandonment process (type of agriculture, landscape type, socio-economic statistics...)

LCF62 Withdrawal of farming without significant woodland creation: Farmland abandonment in favour of natural or semi-natural landscape (except forests and transitional woodland shrub), as long as they are a possible transition. Some odd cases are provisionally recorded as

LCF99 Other changes and unknown

LCF7 Forests creation and management: Creation of forests and management of the forest territory by felling and replanting. Due to the CLC cycle of 10 years, only one part of the shrubs are tall enough to be identified as trees. In order to taking stock of all recent plantations, conversions of semi-natural land to CLC324 are conventionally recorded as afforestation (although some natural colonisation may take place). In the case of conversion from farmland, see LCF61

LCF71 Conversion from transitional woodland to forest: Conversion from transitional woodland to broadleaved, coniferous or mixed forest, taking place when shrubs can be detected as trees

LCF72 Forest creation, afforestation: Forest creation and afforestation take place on all previously non-agricultural landscapes where new forests can be identified. Extension of transitional woodland shrub over non-agricultural land is recorded as afforestation. Conversion from transitional woodland to broadleaved, coniferous or mixed forest are not a creation of forest territory and are therefore registered separately (LCF71)

LCF73 Forests internal conversions: Conversions between broadleaved, coniferous and/or mixed forest (CLC311, 312 and 313)

LCF74 Recent felling and transition: Conversion from broadleaved, coniferous and/or mixed forest to open semi-natural and natural dry land resulting more likely from felling. The main transition is towards CLC324 Transitional woodland shrub, although some other types can be detected. Due to uncertainties, all are provisionally considered as transitional states of forests

LCF8 Water bodies creation and management: Creation of dams and reservoirs and possible consequences of the management of the water resource on the water surface area

LCF81 Water bodies creation: Extension of water surfaces resulting from the creation of dams and reservoirs

LCF82 Water bodies management: Consequences of the management of the water resource on the water surface area of reservoirs

LCF9 Changes of land cover due to natural and multiple causes: Changes in land cover resulting from natural phenomena with or without any

human influence

LCF91 Semi-natural creation and rotation: Changes in natural and semi-natural land cover due to natural factors

LCF911 Semi-natural creation: Natural colonisation of land previously used by human activities. Note that extension of CLC324 is considered as

the result of farmland abandonment or direct afforestation

LCF912 Semi-natural rotation: Rotation between the dry semi-natural and natural land cover types of CLC (except forest and transitional woodland shrub)

LCF913 Extension of water courses: Results from natural erosion and artificial works. Due to the very incomplete detection of rivers with CLC, the LCF913 flow item has to be used very carefully

LCF92 Forests and shrubs fires: Due to the short cycle of recovery of vegetation from fire, burnt areas (which are well identified on satellite images) cannot be compared in a ten-year interval, except for very aggregated statistics

LCF93 Coastal erosion: Conversion of all land cover types to intertidal flats, estuaries or sea and ocean. The tide level when the satellite image is shot being unknown of the photointerpretors, the coastal erosion flow has to be used very carefully

LCF94 Decrease in permanent snow and glaciers cover: Decrease of permanent snow and glaciers due to climate change to semi-natural and natural land covers, mainly to bare rock, sparsely vegetated areas and water systems

LCF99 Other changes and unknown: In this category are recorded land cover changes that are rare or more likely improbable

Annex IX. Reclassified CORINE LC nomenclature for LCM testing

	CLC label	New class code		CLC code
1	Continuous urban fabric	1	Residential	111
2	Discontinuous urban fabric	1		112
3	Industrial or commercial units	2	Industry	121
4	Road and rail networks and associated land	2		122
5	Port areas	2		123
6	Airports	2		124
7	Mineral extraction sites	2		131
8	Dump sites	2		132
9	Construction sites	2		133
10	Green urban areas	3	Recreation	141
11	Port and leisure facilities	3		142
12	Non-irrigated arable land	4	Homogenius Agriculture	211
13	Permanently irrigated land	6	Intensive agriculture	212
14	Rice fields	6		213
15	Vineyards	4	Homogenius Agriculture	221
16	Fruit trees and berry plantations	4		222
17	Olive groves	4		223
18	Pastures	5	Grassland	231
19	Annual crops associated with permanent crops	7	Heterogenious agriculture	241
20	Complex cultivation patterns	7		242
21	Land principally occupied by agric, with natural vegetation	7		243
22	Agro-forestry areas	7		244
23	Broad-leaved forest	9	Broadleaved/mixed forest	311
24	Coniferous forest	8	Coniferous/young forest	312
25	Mixed forest	9	Broadleaved/mixed forest	313
26	Natural grasslands	5	Grassland	321
27	Moors and heathland	5		322
28	Sclerophyllous vegetation	5		323
29	Transitional woodland-shrub	8	Coniferous/young forest	324
30	Beaches, dunes, sands	10	Bared land	331
31	Bare rocks	10		332
32	Sparsely vegetated areas	10		333
33	Burnt areas	10		334
34	Glaciers and perpetual snow	10		335
35	Inland marshes	11	Wetland	411
36	Peat bogs	11		412
37	Salt marshes	11		421
38	Salines	2	Industry	422
39	Intertidal flats	11	Wetland	423
40	Water courses	12	Water	511
41	Water bodies	12		512
42	Coastal lagoons	12		521
43	Estuaries	12		522
44	Sea and Ocean	12		523