A High Resolution Land Use/Cover Modelling Framework for Europe: Introducing the EU-ClueScanner100 Model

Carlo Lavalle[1], Claudia Baranzelli[1], Filipe Batista e Silva[1], Sarah Mubareka[1], Carla Rocha Gomes[1], Eric Koomen[2], and Maarten Hilferink[3]

[1] European Commission, Joint Research Centre,
Institute for Environment and Sustainability,
Land Management and Natural Hazards Unit, Via E. Fermi, 2749,
21027 Ispra (VA), Italy
{carlo.lavalle,claudia.baranzelli,filipe.batista,sarah.mubareka,
carla.rocha-gomes}@jrc.ec.europa.eu
[2] Faculty of Economics and Business Administration,
VU University, De Boelelaan 1105,
1081 HV Amsterdam, the Netherlands
e.koomen@vu.nl
[3] Object Vision BV p/a Vrije Universiteit, De Boelelaan 1085,
1081 HV Amsterdam, The Netherlands

Abstract. In this paper we introduce the new configuration of the EU-ClueScanner model (EUCS100) that is designed for evaluating the impact of policy alternatives on the European territory at the high spatial resolution of 100 meters. The high resolution in combination with the vast extent of the model called for considerable reprogramming to optimize processing speed. In addition, the calibration of the model was revised to account for the fact that different spatial processes may be prominent at this more detailed resolution. This new configuration of EU-ClueScanner also differs from its predecessors in that it has increased functionalities which allow the modeller more flexibility. It is now possible to work with irregular regions of interest, composed of any configuration of NUTS 2 regions. The structure of the land allocation model allows it to act as a bridge for different sector and indicator models and has the capacity to connect Global and European scale to the local level of environmental impacts. The EUCS100 model is at the core of a European Land Use Modelling Platform that aims to produce policy-relevant information related to land use/cover dynamics.

Keywords: Land use/cover; Modelling; Europe; Land demand; Factor data.

1 Introduction and Background

A land-use/cover model is an "*interpretive framework*" [1] of the interactions between different non-linear systems (bio-physical and human) that influence the dynamics of

B. Murgante et al. (Eds.): ICCSA 2011, Part I, LNCS 6782, pp. 60–75, 2011.

Land Use/Cover Change (LUCC). Land-use/cover depends on natural systems, but also, as a product of a society, is constrained and driven by demographic, economic, cultural, political, and technological changes [1]. Besides, land-use/cover is among one of the most important determinants of landscape, local climate conditions, biodiversity, and is relevant for biophysical systems and processes and for most land functions [47] and ecosystem services (de Groot *et al.*. 2002, de Groot *et al.*. 2009). However, the results of these interactions are not fully predictable since "*complex systems generate a dynamic which enables their elements to transform in ways that are surprising, through adaptation, mutation, transformation*" [3]. Based on assumptions regarding the future (what-if scenarios), LUCC simulations are relevant elements for structuring discussion and debate in a decision-making process, but do not present the future itself.

Therefore, and considering that land is a finite resource where competing claims interact, LUCC models emerge as an advanced tool to assess the *ex-ante* consequences of different policy options with spatial relevance and thus can be considered as a spatial decision support system. In 2002, the introduction by the European Commission of the Impact Assessment procedures [7] contributed to consolidate the importance of this tool and to multiply the examples of its application in providing scientific support to policy makers, at a European scale. This is due to the fact that the aim of the Impact Assessment procedures is to provide "evidence for political decision-makers on the advantages and disadvantages of possible policy options by assessing their potential impacts" [37].

Several models which can be linked to the impacts of policy alternatives are available today. The European Environmental Agency provides an overview of the models available to simulate environmental change at European scale [13], focusing on those that can support "*forward-looking environmental assessments and outlooks, as well as models that provide outlook indicators of environmental trends*". Nearly a hundred modelling tools are inventoried according to thematic focus (agriculture, biodiversity, climate, land-use, etc.), geographical scale (global, European, regional) and analytical technique (equilibrium model, empirical-statistical models, dynamic system models, and interactive models). This comprehensive list is a sign of the increasing importance of supporting decision making in such a cross-sector field as environmental issues, and more specifically land use management.

Regarding LUCC, many European projects integrate land-use/cover modelling tools to support policy-making. Among others, the EURURALIS project [47] appears as one of these examples, where the Dyna-CLUE model [43] was used to assess the policy impact of CAP measures post-2013 [21]. Another example is the PRELUDE (PRospective Environmental analysis of Land Use Development in Europe) project [12] that used the Louvain-la-Neuve model to assess the environmental implications of LUCC in Europe, by providing quantitative land use/cover change modelling analyses of the scenarios that were defined through a participatory exercise. A modelling approach was also at the core of integrated projects funded by the EU Framework Programme 6, such as SENSOR [22], which aimed to develop *ex-ante* Sustainability Assessment Tools (SIAT) to support policy making for land use in Europe [2].

In the scope of the EU FP6, some specific targeted research projects were developed with the aim of giving scientific support to policy-making. An example is the CAPRI-Dynaspat project, which aims to develop tools and methods to perform ex-ante policy assessment of the Common Agricultural Policy (CAP) based on the CAPRI model. This model is operational at DG-AGRI. In addition, it is also worth to mention FARO-EU (Foresight Analysis of Rural areas Of Europe), which had the objective of providing guidance for future rural development policies in Europe. In order to accomplish this main goal, and to "assess medium term future of rural areas in terms of economic, environmental social and institutional developments by considering sustainability conceptual framework and under alternative policy scenarios" (http://www.faro-eu.org) a chain of models was used (ESIM-CAPRI-LEITAP/IMAGE-CLUE-s).

Since 1998, the Joint Research Centre has been involved in the development of land use modelling. A first step was taken with the MURBANDY (Monitoring Urban Dynamics) project, whose aim was to monitor the dynamics of urban areas and to identify spatial trends at a European scale [28]. In 2004, collaboration between RIKS and JRC originated the follow-up project MOLAND (Monitoring Land Use Changes (http://moland.jrc.ec.europa.eu) [27], whose aim was to "provide a spatial planning tool for monitoring, modelling and assessing the development of urban and regional system" and also to contribute to mitigation of natural hazards [16].

In 2008, DG Environment identified the need to perform integrated assessments including spatial perspectives, and initiated the *Land use modelling – implementation* project which consisted in defining "an integrated land use modelling framework that can support policy needs of different DGs of the European Commission, such as *ex-ante* assessments and more specific impact assessments" [30]. In order to accomplish this goal, it was decided to use available well-established models. The land-use/cover modelling platform chosen, EU-ClueScanner 1km (EUCS1k), is an evolution of the land use allocation model Dyna-CLUE [46], [44] and [43], which in turn is a version of the CLUE model [39]. EUCS1k brought its predecessors to an open source programming environment, the Geo Data and Model Server (GeoDMS), and was built upon a multi-scale approach that integrates sector models whose role is to translate global and regional LUCC drivers into demand for land. The outcome of the land-use/cover simulation results are assessed through a set of indicators that can be either embedded in the model structure or processed *a posteriori*. EUCS1k is currently operated by the JRC.

In parallel, the JRC initiated the development of an integrated framework in "support to the conception, development, implementation and monitoring of EU policies" (http://ec.europa.eu/dgs/jrc/index.cfm?id=1370). Such a framework, defined as the Land Use Modelling Platform (LUMP), aims to integrate explicit land use models with other modelling activities in specific thematic fields, such as hydrology, agriculture, forestry, etc., and to support the *ex-ante* assessment of different policies.

Our land use modelling platform is currently based on three complementary LUCC models so to be able to cope with applications requiring high spatial resolution such as the simulation of urban areas; and pan-European applications. While the first purpose is served by the MOLAND model, the second makes use of EUCS1k.

As operational work began with land use modelling, it became evident that a new model was required to fill certain gaps. The evolution of the EUCS100 model is based on the structure of the EUCS1k model described above. EUCS100 and EUCS1k share several algorithms and processes, but EUCS100 has extended and improved capabilities which we will describe in detail throughout this paper. To summarise, EUCS100 is able to treat demand sets at NUTS 2 regional level and has a simplified and lighter configuration than its parent model EUCS1k. EUCS100 allows for multiple land use typologies and multiple regional divisions, as well as multiple simulation periods. A significant improvement is the benefit of modelling at the same scale as the Corine Land Cover input. Another important evolution in the EUCS100 version with respect to its 1km parent is the tiling of the images, saving valuable processing time and physical disk space. Furthermore, EUCS100 now converts maps to the ETRS 1989 reference system on the fly, and thus complies with the Inspire Directive (http://inspire.jrc.ec.europa.eu). These advantages translate to a higher degree of flexibility in terms of applications of the land use model.

The possibility to apply the most appropriate combination of explicit LUCC models amongst the three available (EUCS100, EUCS1k and MOLAND) represents a unique and powerful opportunity for the evaluation of impact of new or revised policies in Europe. This paper aims to give an overview of the land use/cover model EUCS100. Presently, the model is still under development, and some of its features are being improved. In section 2 its main characteristics are described, followed by an explanation about the structure of the model, in section 3. Lastly, section 4 provides an insight of the work undertaken to calibrate and validate EUCS100. We conclude with final remarks on the challenges to be addressed in future developments.

2 General Overview of the Model and Novelties

EUCS100 is a land allocation model whose main purpose is to support decision making by assessing *ex-ante* policy options in different sectors for the extent of the European Union. The main outputs of EUCS100 are projected land use/cover maps for a specified time in the future. Therefore, impact assessment of policy alternatives can be made specifically in the domain of land use/cover change and its direct or related implications in the context of different applications and studies.

To project land-use/cover into the future, EUCS100 uses known information on the drivers and determinants of LUCC. This information is mainly extracted from the analysis of observed LUCC. In this modelling environment, land-use/cover is depicted in a raster environment. EU-ClueScanner is implemented in GeoDMS (Geo Data and Model Server), which is a programming language optimized for raster operations and was developed and made freely available by Object Vision (http://www.objectvision.nl) as a stand-alone software optimized for desktop computers, provided with a graphical user interface. GeoDMS is a high level programming language that allows 1) transparency regarding the algorithms; 2) continuous improvement and debugging; 3) the management of large raster datasets; and 4) is fit for modular development of extra features and linkages with other models. The GeoDMS also underlies the much-applied Land Use Scanner model (e.g. [23], [25] and [26]).

The characteristics of the model are summarized as follows. It is modular because it is organized in three main components: land demand module, land allocation module and indicator module. It is sector integrative, mainly because land allocations are primarily driven by forecasts in the socio-economic sector at national or regional level. Simulations are yearly based, since there is a projected land-use/cover map for every year from the starting until the ending year of the simulation. It is recursive because simulation results for year *n* are used for the simulation of the year *n+1*. It is statistical because drivers for LUCC are inferred statistically from historic land-use/cover patterns, their neighbourhood relationships and their dependence on physical or socio-economic factors and it is European-wide because it provides simulations for continental Europe. Configured to run with 1 hectare cells (100 m x 100 m), it is considered a very high spatial resolution model. The latter two characteristics constitute together the major improvement of the model compared to previous land-use/cover modelling frameworks.

In the current configuration of the model, the land-use/cover legend is derived from Corine Land Cover (CLC) encompassing a total number of 44 different land-use/cover classes. EU-ClueScanner is capable of dealing with different legend configurations of CLC, each configuration being a different combination of land-use/cover class aggregations. This is a useful feature in order to adapt to different assessment requests. Furthermore, since the model can technically deal with any land-use/cover class for which processes and suitability factors are known, it is not strictly dependent on CLC as source of land-use/cover input.

Each class used in the model falls into one of the three following categories: active classes, passive classes and fixed classes. Active classes are those for which land demand can be exogenously determined using external sector models or projections. Examples of these classes are the built-up areas (residential, industrial or commercial), agriculture and forest. Passive classes are governed primarily by the dynamics of the active classes, as no specific demand has to be defined. Semi-natural land use types typically fall into this category. Finally, the fixed classes are those that remain spatially fixed during the simulation. Fixed classes are those for which processes, demands and suitability criteria are not known or cannot be modelled with current knowledge/data. Examples of fixed classes are water bodies, wetlands, burnt areas and some natural areas like bare rocks, beaches, dunes and glaciers. This categorization of land-use/cover classes is similar to the ones adopted in other modelling frameworks, such as in Moland [27] or Dyna-Clue [43].

3 Structure of the Model

EUCS100 has three main modules (Fig. 1). The first module integrates land claim data derived from external models. These external models take global factors into consideration and are subject to change according to the scenario modelled. The second module consists of the core of EUCS100 and is a dynamic simulation procedure that is the same as in the dyna-Clue model [43]. Starting from the current land use/cover map, the algorithm is designed so that in a specific location, a certain transition from one land use/cover to another actually takes place only if the overall suitability assigned to the latter is higher than the ones assigned to the other land use/covers which are competing for that location. The overall suitability is built up of several elements, namely factor data, neighbourhood effect, location specific drivers, conversion costs. All those elements are designed in order to allow the definition and implementation of EU policy alternatives.

The third module translates the projected land use/cover maps generated at annual time steps to formats usable for impact analysis. As shown in Figure 1, land use/cover based or thematic indicators are computed by built-in algorithms.

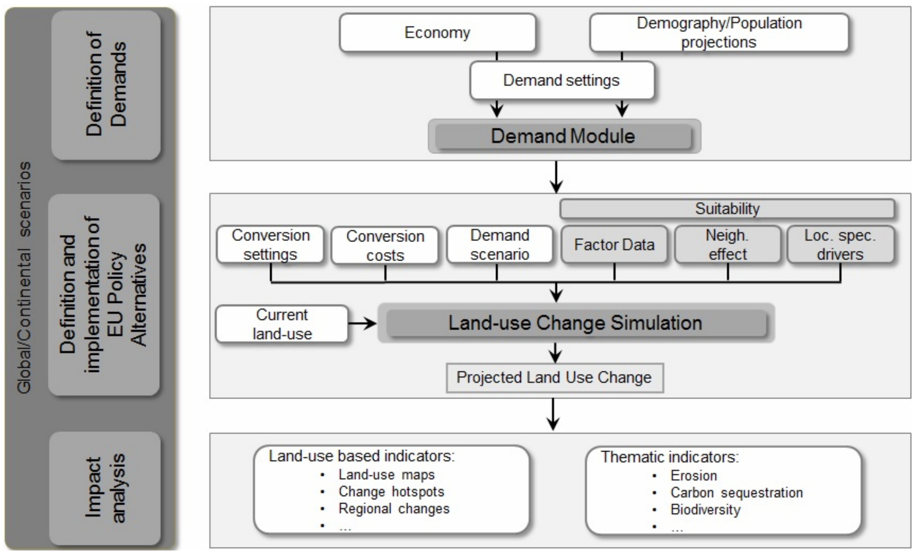

Fig. 1. Overall workflow of EUCS100 highlighting the three main modules of the model

3.1 Demand Module

As shown in Fig. 1, the demand module is the first stage of the modelling workflow. Its purpose is to provide an input for the land allocation module specifying the amount of land per each active land-use/cover class per region. These regions can be any combination of NUTS levels depending on availability of land demand data. Ideally, the total amount of land available is equivalent to the total amount of land required by all sectors. The sources of the demand sets themselves differ substantially depending on the sector. As an example, demographic and employment dynamics, as well as housing market trends are important drivers of residential land developments. A different angle is taken for arable land demand sets. Market conditions, demand for agricultural commodities and public policies are among a number of other relevant factors. Once demands are set for the required land-use/cover classes, the land allocation module allocates the extra land requirements at the pixel level.

We emphasize that 'land claims' are different from 'land demand'. The former is derived from the latter, and is modified to account for regional areal constraints. Land claims are the actual figures to be allocated.

Demand for Artificial Land-Uses/Covers

Since natural growth has been declining in Europe, the modest population growth rate is mainly attributable to immigration. The demographic profile is changing: population is aging and while the number of family nuclei is increasing, their mean size is decreasing. These changes affect future demand for housing. It has also been signalled that the increase of unstable jobs and the foreseen loan restrictions may temper some of the dynamics [35]. In another study, different approaches for calculating future residential land use demand in the context of land-use/cover modelling are reviewed [24]. Three main categories were identified: 1) trend extrapolations, 2) regression models and 3) density measures.

The third approach makes use of density measures, such as population density, to compute urban land demand. Historical measures of density can be kept constant or be dynamically modified during simulation. Then, these measures, together with demographic projections, may be used to estimate marginal urban land demands.

The density approach is taken in EUCS100 to derive residential land demand. Firstly the historical trends in density measures (inhabitants / built-up area) for each region are computed using time series for population (Eurostat) and for urban land (CLC). In a second step, density measures are extrapolated up to 2030 using past trends. Lastly, population projection figures[1] are used together with the densities to estimate future urban land use demands.

In EUCS100, industrial or commercial units are modelled separately from the predominantly residential urban fabric class. The modelling of this class poses a number of challenges. The first is related to the heterogeneity of the class itself as defined in CLC. This class in CLC includes two very different components: industrial and commercial units, which makes isolating the appropriate LUCC driving factors very difficult. The second challenge is related to identifying a source for the demand for these areas. As seen previously, it is possible to conceive a relationship between demographic dynamics, population density trends and requirements for new urban land. But for the case of land demand for industry and commercial areas, the relationship involves more variables and is less straightforward.

It is noteworthy that demand for non-residential built-up areas will be more difficult to model for the next decades due to the transformation of the nature of work and employment patterns that are “creating unstable demands for land use” [35]. While Pratt [35] provides extensive and pertinent considerations on the social and economic drivers of LUCC from a very disaggregated perspective – the firms and the households –, our modelling framework, however, must deal with aggregated trends at regional level, usually expressed by macro-economic indicators, from which demand must be inferred. Consequently, aggregated economic sector perspectives at regional level must be used in an adequate regression model to estimate overall demand. Such a work is currently under development.

Demand for Agriculture and Forest

The agricultural land demand is given by the Common Agricultural Policy Regionalised Impact analysis model (CAPRI). The CAPRI economic model was developed in the late nineties with the scope of modelling the agricultural sector on an EU scale [4] and [5]. CAPRI relies on several datasets (Eurostat, FAOSTAT and OECD) and compiles them into a single complete and consistent database (CoCo). It

[1] EUROPOP2008 population projection from Eurostat will be used, as it is considered to be, at the moment, the best available guess regarding future population development. It estimates population by sex and age by NUTS2 region, up to 2031 in annual time steps.

has two major modules: the supply and the market modules. The first module is able to capture the premiums paid under the Common Agricultural Policy (CAP), taking the feeding activities, nutrient requirements of animals and set-aside land obligations, milk quotas and the sugar quota. The market module feeds the supply model with prices through an iterative process.

The data used from CAPRI are Supply details for farms for 1990-2005 (several other indicators are available in the database from 1984-2005). Data is available for all countries in the EU plus Norway, Western Balkans and Turkey, with some data holes where data could not be inferred. In addition to this historical data which we will use for validating the methods described later in this paper, the results for the baseline scenario run are available for 2020 for all NUTS 2 regions for the regions mentioned above.

For forecasts in the agricultural sector, we rely on the CAPRI baseline scenario output for 2020 for agriculture. This baseline scenario is generated in harmony with DG AGRI's outlook projections and can be described as the most probable future development for the agricultural sector in Europe.

Finally, a dedicated module is currently being developed for the evaluation of forest land demand. The module firstly quantifies the demand for services and products provided by the forest in response to various drivers such as market (for wood and non-wood products), policy (e.g. CAP, renewable energy policies), environment (e.g. climate, extreme events, demand for ecosystem-based services) and socio-economy (e.g. population growth, GDP). Relevant data come from existing and well acknowledged sources such as EUROSTAT, FAO, EU funded projects, the UN-ECE EFSOS Committee. These also provide sector outlooks and foresight studies. The second step is the actual computation of forest area demand, which could be either positive or negative, at the most appropriate geographical aggregation level.

3.2 Land Allocation Module

EUCS100 is able to process land demand data for any combination of NUTS1 and NUTS2 regions, and not only at national level, as its predecessor EUCS1k did. Another improvement in this version of the model is that in order to deal with the uncertainty inevitably brought into our approach by the linkages with other models delivering demands of land, it is possible to translate those demands into ranges of claims, i.e. minimum and maximum claims, for each modelled land use/cover class. This approach emphasizes the role of the complex of spatial interactions carried out by the allocation module. The mechanism is implemented in a way that, if the total amount of available land (i.e. the area of the region minus the area of the fixed classes) is below the sum of minimum demands, the minimum claims are adjusted so to take into account that threshold, while the maximum claims hold steady. On the contrary, having more land use/cover at its disposal as land prone to be potentially changed than the actual total amount of maximum demands allows the model larger maximum claims for each land use/cover. To take matters further, implementation of a spill-over effect it is currently being considered. This implies that when the demand is not met within the region for which it has been defined, the excess quantity of LUCC can be transferred to neighbouring regions. The rules about the definition of these neighbourhoods can be either policy-related or taking account for known local/regional economic dynamics.

Suitability

Land use and land cover models deal with the interactions and competitions among different land use/cover classes, thus facing a complex system in which several cross-scale dynamics take place [45]. All the processes involved may relate to variables (either exogenous or endogenous with respect to the land use/cover system), commonly referred to as driving forces (e.g. demographic, economic dynamics, bio-physical characteristics). Thus, according to our approach, factor data represent exogenous factors responsible for the land use/cover change dynamics.

In order to quantify the relation between driving forces and land use/cover, an inductive approach is implemented, thus meaning that the suitability of a location for a certain land use/cover is determined in an empirical way by means of a regression analysis [29]. This approach applies for both the core elements which define the overall suitability (factor data and neighbourhood effect). Nevertheless, it is noteworthy that the inclusion of economic or social factors is often reduced due to a lack of spatially defined data and methodological issues regarding the knowledge of specific cause-effect relations. Indeed, it often happens that proxy variables in place of underlying driving forces are included in the modelling framework [40].

The current configuration of EUCS100 enables to process large datasets, as they are meant to be factor data relevant at a fine resolution (100m) and available for a wide territory (the entire European territory).

As for socio-economic factors, accessibility patterns are considered a major driver of land use/cover change at regional and local level due to their importance as location factor for both households and firms [17]. Accessibility is defined depending on the type of both origins and destinations it is computed for, and the considered transportation system. Several definitions and respective measures can be found in a rich bibliography (see [8], [15], [17], [18]).

In the context of LUMP, accessibility depends on travel origins, travel destinations and characteristics of the transportation network (e.g. geometry, speed limit). Accessibility is used in EUCS100 mainly as a factor for the allocation of residential and industrial land use classes. Several location-based accessibility maps have been thus produced, each taking into account a different set of destinations, i.e. main nodes of transport (ports and airports), entry points of high-speed road networks (freeway and highway entries/exits), major European cities and towns of regional importance. The set of origins is invariant and has been implemented to mimic real travel origins (nearly 200.000 points across Europe). The network used in the analysis was obtained from the Transtools project, completed, in some regions, by TeleAtlas 2008 network. An origin-destination matrix was finally computed whereby each origin is assigned the travel cost to the closest destination. The final maps in raster format are then obtained from the spatial interpolation of travel cost assigned to origins.

Proximity to roads of regional/local importance is strongly correlated with new urban developments (as examples, see [31] and [32]). In order to take into account these local dynamics of land use/cover change, a distance to road map has been produced. This has been computed with respect to TeleAtlas 2008 network, including motorways, major roads of high importance, secondary roads, local connecting roads, local roads of high importance and local roads.

Besides driving forces strongly related to transportation systems, other explanatory variables for LUCC dynamics are particularly relevant to the location of semi-natural classes (e.g. semi-natural vegetation, woods, agricultural land). The European Soil DataBase (ESDB) constitutes a reliable point of reference for representing soil properties: this database contains a list of Soil Typological Units (STU), characterizing distinct soil types. Each STU is then described by attributes (variables) specifying the nature and properties of the soils, e.g. texture, moisture regime, stoniness, etc. The richness in information allows, depending on the specific land use/cover taken into account, to include as a respective relevant factor map a (combination of) specific soil characteristics. Detailed factor maps have been prepared also regarding other geomorphological properties, such as the slope (from Global Digital Elevation Model - SRTM).

The so called neighbourhood effect is in charge of modelling proximity interactions (i.e. interactions between neighbouring land use/cover types) between land use/cover types. As many authors have pointed out (see [41], [11], [20] and [19]), neighbourhood plays a major role in the land use/cover change dynamics. The definition (characteristics/parameters) of the neighbourhood function is a demanding task. In fact, there are region and temporal variability issues: the neighbourhood effect may change among different regions and across time [41]. Another issue can be pointed out: depending on the scale of analysis, different neighbourhood relations emerge. As a consequence of the previous issues, particular attention has to be paid to the necessity of including in the modelling framework only independent variables: as the time scale lengthens, many explanatory factors become endogenous [11].

Location Specific Drivers

Suitability maps for each modelled land use/cover class can be altered where a policy or a combination of policies applies. This concept, which was first implemented in the CLUE-s model [49] and [48], was carried over to EUCS100 in order to reflect spatially explicit European policies. It is possible to combine the consequences of policies which award subsidies/incentives for the presence of a specific land use/cover in a unique land use/cover specific map thus increasing the respective local suitability, as well as policies targeted at discouraging the presence of a land use/cover: in the latter case the local suitability will be lowered.

Conversion Settings and Conversion Costs

The matrix responsible for setting the allowed conversions between land-use/cover classes overrules the computation of the overall suitability. It is possible to make land use/cover changes more or less dependent on the local land use/cover history [6]. A certain land-use/cover configuration/pattern can be made stable so to take into account the previous states of the modelled system [49].

Current Land use/cover Input

The starting point of the simulation is given by CLC 2006. The CLC is the only European wide land-use/cover map that is consistent across space and inter-comparable among temporal releases (1990, 2000, and 2006). This is due to the common guidelines that have been followed by the image interpreters since the first version of the CLC. The minimum mapping unit (MMU) of CLC was initially set to 25 ha. This characteristic constitutes a limitation of CLC. In practical terms, it means that any object on the Earth's surface with less than 25 ha in size is not mapped. This parameter has a considerable implication in the identification of urban areas, especially in low density territories with sparse and/or sprawled settlements, where part of the urban land-use/cover is, in fact, not captured. Ideally, all existing urban land should be accounted for modelling purposes. The dissimilarity between the reality and the model's land-use/cover map input is probably the very first contributor for error propagation.

To address this issue, an improvement of the initial CLC map was designed and prepared using finer datasets produced and/or available at JRC. The improvement targets spatial detail by reducing the minimum mapping unit to 1 ha (1 raster cell) whenever possible for the same legend nomenclature. Datasets used in this refinement are: Soil Sealing Layer, Urban Atlas, TeleAtlas and SRTM water bodies.

3.3 Indicators Module

A subset of the indicators described in [14], derived from the EURURALIS framework, is currently implemented in EUCS100. These indicators are embedded inside of the GeoDMS environment and can be generated as maps or as tables and can be aggregated from cell-based indicators to indicators at any regional configuration, allowing the possibility to compare the impacts of the different policy alternatives.

There are two large families of indicators: Land use related and thematic. The land use related indicators put into evidence the most prevalent *changes from* and *changes to* land-use/cover classes and shows the land change hotspots for agricultural land abandonment or expansion and urban expansion. The thematic indicators calculated at the 100m level in EUCS100 are land cover connectivity potential, soil sealing, river flood risk and urban sprawl. Like the land use/cover related indicators, the thematic ones are calculated on a per cell level and can be aggregated at various levels. A full description of these indicators is in [30].

4 Calibration and Validation

As it is to be expected that spatial processes may have different impacts at different scales, the new 100m resolution version of the model needed a revision of the calibration that was initially performed at a 1km scale.

In order to ensure a realistic distribution of land cover classes throughout time, given an evolving demand set and dynamic neighbourhood, EUCS100 is calibrated according to the situation depicted by CLC in 1990. The model calibration is performed using a multinomial logistic regression to establish the most suited parameter sets to describe the probable location of a certain land cover class among all of the endogenous land cover classes. The dependant variable is therefore an endogenous land cover class and the independent variables are the series of factor maps described in section 3.2. The neighbourhood effect is taken into account separately in a second multinomial logistic regression that assesses the land composition of the three rings of cells directly neighbouring the observed (to be explained) cells of each endogenous land cover class. This separate assessment of more general driving forces thought to be operating at a coarser scale and the local neighbourhood relations has the advantage of accounting for spatial autocorrelation.

The analysis is done at national level, with the exception of small countries which are grouped in order to assure an adequate amount of samples. Thus the calibration parameters are country specific in order to reflect the different driving forces behind the land use patterns and changes. The parameters are stored in text files in their respective country folders and are read and implemented when a simulation is run.

In order to validate the calibration parameters set through the process described above, the year 2000 was simulated starting with CLC 1990 and compared with the CLC 2000. For the simulation run, the claims per land use type were obtained from the observed amount of that land use type for 2000, as taken from the CLC 2000. For the validation we followed a similar approach to that carried out in a previous assessment of contemporary land-use change models [33] (see also [34] and [38]). That study distinguished three possible two-map comparisons using observed and simulated land use for two time steps:

- observed 1990-observed 2000 characterising the observed land-use change;
- observed 1990-simulated 2000 referring to the land-use change predicted by the model;
- observed 2000-simulated 2000 determining the accuracy of the prediction.

Based on the available maps it is also possible to perform a three-map comparison that allows distinguishing the correct prediction due to persistence of land use from well-predicted changes in land use. This is an important distinction as the amount of change is normally limited. Comparison methods that compare the complete simulation map with the complete observation map are strongly influenced by the static patterns and tend to overestimate the predictive power of land-use models. Therefore it is more meaningful to focus on the amount of correctly predicted change.

Based on the comparisons of the three available maps we can determine both quantity and location agreement between observed and simulated land use patterns. Quantity agreement is obtained by comparing the aggregate totals of all land-use classes in the simulated and observed land use. To describe location agreement we first create the following maps: (A) well-predicted change; (B) observed change predicted, but as a wrong gaining class; (C) observed change predicted as persistence and; (D) and observed persistence predicted as change. Based on these, location agreement was quantified using the following three statistic measurements:

- figure of merit = A / (A+B+C+D), which measures the accuracy of the model in predicting land-use change;
- producer accuracy = A / (A+B+C), which gives the proportion of pixels that the model predicts accurately as change, given the observed change;
- user accuracy = A / (A+B+D), which calculates the proportion of pixels predicted accurately as change, given the model predicted change.

A first validation was carried out for Belgium and Ireland. These two countries were selected as they show a substantial difference in the amount of actual change between

1990 and 2000 (in Belgium only 1.7% of the total land surface changed its use, while in Ireland 8.2 % changed). For reference purposes two statistics have been added to the three measures proposed by [33]: the proportion of well-predicted persistence and the overall model performance indicating the total amount of correctly predicted pixels (thus including correct persistence).

The preliminary results show that well-predicted persistence ranges from 95.6% to 98% and the overall model performance ranges from 88.5% to 96.5% for Ireland and Belgium, respectively. However, figure of merit, producer and user accuracies are below 10%. The preliminary results indicate the relation between model performance and observed amount of change. With more observed change the model is able to obtain higher user accuracy, but this comes at the cost of predicting persistence less well. However, this work is on-going and results are most likely to change. Further work will focus on the inclusion of explanatory variables at a higher resolution. In addition a longer observation period will be included in upcoming validation efforts, making use of the newly released CLC 2006.

5 Conclusions and Way Forward

The EUCS100 model is at the core of the multi-scale, multi-model framework referred to as the European Land Use Modelling Platform (LUMP) that aims to produce policy-relevant information related to land use/cover dynamics. It can support the creation of *ex-post* and *ex-ante* assessments of policies that impact spatial developments. The EUCS100 is a land allocation model that bridges sector models and indicator models and has the capacity to connect Global and European scale to the local level of environmental impacts.

The model is undergoing continuous development in order to answer to specific questions related to different sectors for assessing policy alternatives. In particular, the current version has been being developed in response to increasing requests for a tool capable of 1) modelling at the same resolution as the best current pan-European input maps (i.e. CLC) while being capable of using other sources of input maps; 2) producing meaningful indicators for the monitoring of Europe's territory, requiring high spatial and flexible thematic precision, especially of urban areas; 3) modelling different regionally-defined areas, independently of national borders.

EUCS100 is on the path towards being fully operational. Throughout the development phase, the model has been modified both conceptually and technically. The conceptual modifications include multiple land use typologies and multiple regional divisions, as well as multiple simulation periods. Technical modifications include the way the model handles images through tiling and re-projection capabilities on the fly to adhere to the Inspire Directive. Current and future developments include 1) a full validation procedure using two test cases with observed land claims at NUTS2 level; 2) the development of new pan-European predicted demand sets at NUTS2 level, driven by sector-specific models in forestry, agriculture and built-up classes; and 3) the increase in the flexibility of the system through the reduction in the current model structure complexity, which is a product of years of evolution.

Acknowledgments. Part of the work herein reported is financed by the Directorate General Environment, European Commission. The authors also express their thanks to Vasco Diogo for his relentless efforts in providing revised calibration results.

References

1. Allen, P.M., Torrens, P.: Knowledge and complexity (introduction). Futures 37, 581–584 (2005)
2. Bakker, M., Verburg, P.: SENSOR Project Deliverable Report D 2.2.2/3; Deliverable title: Scenario based forecasts of land use and land management at 1 km^2 grid and NUTS-X level, based on CLUE-S. In: Helming, K., Wiggering, H. (eds.) SENSOR Report Series 2008/09, ZALF, German (2009)
3. Batty, M., Torrens, P.: Modelling and prediction in a complex world. Futures 37, 745–766 (2005)
4. Britz, W.: Automated model linkages: the example of CAPRI, vol. 57(8), pp. 367–368. Agrarwirtschaft, Jahrgang (2008)
5. Britz, W., Witzke, H.P. (eds.): CAPRI Model Documentation 2008: Version 2. Institute for Food and Resource Economics, University of Bonn (2008)
6. Brown, D.G., et al.: Path Dependence and the validation of agent-based spatial models of land-use. Int. J. Geo. Inf. Sci. 19:2, 153–174 (2005)
7. COM 276 - Communication from the Commission on impact assessment (2002)
8. Dalvi, M.Q., Martin, K.M.: The Measurement of Accessibility: some preliminary results. Transportation 5, 17–42 (1976)
9. De Groot, R.S., et al.: Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7(3), 260–272 (2010)
10. De Groot, R.S., Wilson, M.A., Boumans, R.M.J.: A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41(3), 393–408 (2002)
11. Dendoncker, N., Rounsevell, M., Bogaert, P.: Spatial Analysis and Modelling of Land Use Distributions in Belgium. Com. Env. Urb. Sys. 31, 188–205 (2007)
12. EEA (European Environmental Agency): Land-use scenarios for Europe: qualitative and quantitative analysis on a European scale, Copenhagen: European Environmental Agency. EEA Technical report no. 9/2007 (2007)
13. EEA (European Environmental Agency): Modelling environmental change in Europe: towards a model inventory (SEIS/Forward), Copenhagen: European Environmental Agency. EEA Technical report no. 11/2008 (2008)
14. Eickhout, B., Prins, A.G.: Eururalis 2.0. Technical background and indicator documentation. Wageningen University and Research and Netherlands Environmental Assessment Agency (MNP), The Netherlands (2008)
15. El-Geneidy, A.M., Levinson, D.M.: Access to Destinations: Development of Accessibility Measures. Final Report for Minnesota Department of Transportation. In: Networks, Economics, and Urban Systems Research Group/Department of Civil Engineering, University of Minnesota, St. Paul (2006)
16. Engelen, G., et al.: The MOLAND modelling framework for urban and regional land-use dynamics. In: Koomen, E., et al. (eds.) Modelling Land-Use Change, Progress and applications, pp. 297–319. Springer, Heidelberg (2007)

17. Geurs, K.T., Ritsema van Eck, J.R.: Accessibility Measures: Review and Applications – Evaluation of Accessibility Impacts of Land-use Transport Scenarios, and Related Social and Economic Impacts. Report for RIVM – National Institute of Public Health and the Environment (2001)
18. Geurs, K.T., van Wee, B.: Accessibility Evaluation of Land-use and Transport Strategies: Review and Research Directions. J. Tra. Geo. 12, 127–140 (2004)
19. Hansen, H.S.: Empirically Derived Neighbourhood Rules for Urban Land-Use Modelling. Environment and Planning B: Planning and Design advance online publication (2010)
20. Hansen, H.S.: Quantifying and Analysing Neighbourhood Characteristics Supporting Urban Land-Use Modelling. In: Bernard, L., Friis-Christensen, A., Pundt, H. (eds.) Lecture Notes in Geoinformation and Cartography, The European Information Society, pp. 283–299. Springer, Heidelburg (2008)
21. Helming, J.F.M., Janssen, S., van Meijl, H.: mpact assessment of post 2013 CAP measures on European agriculture. LEI report, The Hague (2010)
22. Helming, K., et al.: Ex-ante impact assessment of land use change in European regions—the SENSOR approach. In: Helming, K., Perez-Soba, M., Tabbush, P. (eds.) Sustainability Impact Assessment of Land Use Changes, pp. 77–105. Springer, Heidelberg (2008)
23. Hilferink, M., Rietveld, P.: Land Use Scanner: An integrated GIS based model for long term projections of land use in urban and rural areas. Journal of Geographical Systems 1(2), 155–177 (1999)
24. Hoymann, J.: Accelerating urban sprawl in depopulating regions: a scenario analysis for the Elbe River Basin. Reg.Environ.Change (in press)
25. Hoymann, J.: Spatial allocation of future residential land use in the Elbe River Basin. Environment and Planning B: Planning and Design 37(5), 911–928 (2010)
26. Koomen, E., Borsboom-van Beurden, J.: Land-use modeling in planning practice; the Land Use Scanner approach. Springer, Heidelberg (2011)
27. Lavalle, C., et al.: The MOLAND model for urban and regional growth forecast - A tool for the definition of sustainable development paths, European Commission, vol. 21480, p. 22. DG-Joint Research Centre, Ispra, Italy (2004)
28. Lavalle, C., Ehrlich, D., Annoni, A.: Sustainable urban development: the MURBANDY project of the Centre for Earth Observation. In: IEEE International Geoscience and remote sensing symposium proceedings (IGARSS1998), vol. 5, pp. 2571–2573 (1998)
29. Overmars, K.P., Verburg, P.H., Veldkamp, T.A.: Comparison of a Deductive and an Inductive Approach to Specify Land Suitability in a Spatially Explicit Land Use Model. Land Use Policy 24, 584–599 (2007)
30. Pérez-Soba, M., Verburg, P.H., Koomen, E., Hilferink, M., Benito, P., Lesschen, J.P., Banse, M., Woltjer, G., Eickhout, B., Prins, A.G., Staritsky, I.: Land use modelling - implementation; Preserving and enhancing the environmental benefits of land-use services. Final report to the European Commission, DG Environment. Alterra Wageningen UR/ Geodan Next/ Object Vision/ BIOS/ LEI and PBL, Wageningen (2010)
31. Pijanowski, B.C., Brown, D.G., Shellito, B.A., Manik, G.A.: Using neural networks and GIS to forecast land use changes: a Land Transformation Model. Computers, Environment and Urban Systems, 26, 553–575 (2002)
32. Pijanowski, B.C., Shellito, B., Pithadia, S., Alexandridis, K.: Forecasting and assessing the impact of urban sprawl in coastal watersheds along eastern Lake Michigan. Lakes & Reservoirs: Research and Management 7, 271–285 (2002)
33. Pontius, J. R.G., et al.: Comparing the input, output, and validation maps for several models of land change. Annals of Regional Science 42(1), 11–37 (2008)

34. Pontius Jr, R.G., Huffaker, D., Denman, K.: Useful techniques for validation for spatially explicit land-change models. Ecological Modelling 179, 445–461 (2004)
35. Pratt, A.: Social and economic drivers of land use change in the British space economy. Land Use Pol 114, 109–114 (2009)
36. Rich, J., et al.: Report on Scenario, Traffic Forecast and Analysis of Traffic on the TEN-T, taking into Consideration the External Dimension of the Union – TRANS-TOOLS version 2; Model and Data Improvements. DG TREN, Copenhagen, Denmark (2009)
37. SEC1992 Impact Assessment Guidelines (2009)
38. Van Vliet, J.: Assessing the accuracy of changes in spatial explicit land use change models. In: 12th annual AGILE conference on Geographic Information Science (2009)
39. Veldkamp, A., Fresco, L.O.: CLUE-CR: an integrated multi-scale model to simulate land use change scenarios in Costa Rica. Ecol. Model 91 (1996)
40. Veldkamp, A., Lambin, E.F.: Editorial: Predicting land-use change. Agr. Eco. Env. 85(1-3), 1–6 (2001)
41. Verburg, P.H., de Nijs, T.C.M., Ritsema van Eck, J., Visser, H., de Jong, K.: A Method to Analyse Neighbourhood Characteristics of Lan Use Patterns. Computers, Environment and Urban Systems 28, 667–690 (2004)
42. Verburg, P.H., Eickhout, B., van Meijl, H.: A multi-scale, multi-model approach for analyzing the future dynamics of European land use. Annals of Regional Science 42(1), 57–77 (2008)
43. Verburg, P.H., Overmars, K.: Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landscape Ecology 24(9), 1167–1181 (2009)
44. Verburg, P.H., Rounsevell, M.D.A., Veldkamp, A.: Scenario-based studies of future land use in Europe. Agriculture, Ecosystems & Environment 114(1), 1–6 (2006)
45. Verburg, P.H., Shot, P.P., Dijst, M.J., Veldkamp, A.: Land Use Change Modelling: Current Practice and Research Priorities. Geo.J. 61, 309–324 (2004)
46. Verburg, P.H., Soepboer, W., Limpiada, R., Espaldon, M.V.O., Sharifa, M.A., Veldkamp, A.: Modelling the spatial dynamics of regional land use: The CLUE-S model. Environmental Management, 30, 391–405 (2002)
47. Verburg, P.H., van de Steeg, J., Veldkamp, A., Willemen, L.: From land cover change to land function dynamics: A major challenge to improve land characterization. J. Environ. Manag. 90, 1327–1335 (2009)
48. Verburg, P.H., van Eck, J.R.R., de Nijs, T.C.M., Dijst, M.J., Schot, P.: Determinants of land-use change patterns in the Netherlands. Environment and Planning B: Planning and Design 31(1), 125–150 (2004)
49. Verburg, P.H., Veldkamp, A.: Projecting land use transitions at forest fringes in the Philippines at two spatial scales. Landscape Ecology 19, 77–98 (2004)