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PAŃSTWOWY INSTYTUT BADAWCZY
INSTITUTE OF SOIL SCIENCE AND PLANT CULTIVATION
STATE RESEARCH INSTITUTE

Tomasz Stuczyński

ASSESSMENT AND MODELLING OF LAND USE CHANGE IN EUROPE IN THE CONTEXT OF SOIL PROTECTION

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I ROZPRAWY
NAUKOWE

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1. INTRODUCTION

The interest in land use studies has been evolving quickly in the last decade, and some researchers have even proposed distinguishing a new discipline called land use science (Foley et al., 2005; Gutman et al., 2004; Rindfuss et al., 2004). This new emphasis on landscapes, their functions and concepts concerning their sustainability is a response by the research community to a need to minimize the depletion of land resources and to environmental and social impacts caused by land use change. Changes are not limited to land cover only, but potentially lead to disturbance of landscape functions. Land use change-related pressures on ecosystems and societies are inherent consequences of economic and social growth, and as such cannot be entirely avoided. However, it is of vital importance to the global community to establish a balance between the increasing demand for goods and services, and environmental quality. This is how the sustainable development paradigm is defined today (Iyer-Raniga & Treloar, 2000). It has been accepted that land use change has important consequences for global and regional climates, and global biogeochemical cycles such as carbon and nitrogen, biodiversity and water quality (Vitousek et al., 1997; Williams, 2000; Goldewijk & Ramankutty, 2004). Models, calibrated on the basis of historical census data, tax records and land surveys, indicate that global cropland areas expanded from 3-4 million km^2 in 1700 to 15-18 million km^2 in 1990, mostly at the expense of forests (Richards, 1990; Goldewijk & Ramankutty, 2004). Currently in the EU, most of the changes which can be detrimental, leading to a loss of soil functions, mainly concern land flows from agriculture into artificial, impermeable surfaces – although there is also a positive trend in afforestation (EEA, 2006a), which is likely to continue in the future (Nowicki et al., 2007).

Urbanization and spatial development can be considered as pressures on landscape diversity, potentially reducing its buffering capacity and resilience to degradation (Antrop, 2004). An evaluation of these pressures is of fundamental importance in the context of soil framework strategy, which is aimed at protecting soils and their functions (COM 231, 2006). The strategy presented by the European Commission identifies a number of threats to maintaining soil functions in Europe: erosion, decline of organic matter, local and diffuse contamination, sealing, compaction, decline in biodiversity, salinisation, floods and landslides. Land use change, and, in particular, urbanization of agricultural land, may accelerate these processes. According to the proposal for the Soil Directive (COM 232, 2006), European Union member states will be required to assess the impact of urbanization and subsequent soil sealing, which lead to a loss of habitat and retention functions of landscapes.

In order to formulate relevant future policy and devise appropriate instruments it is of vital importance to learn how spatial development has affected soils across Europe – this subject, so far, has not been adequately addressed on an EU scale. Very little information exists on how urbanization, infrastructural development and afforestation, taking place at the expense of agricultural land, spreads relative to

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the spatial distribution of soil erosion risk, soil organic matter content, land suitability for crops, water retention capacity, contamination and other quality/degradation indicators. It is important to mention that we cannot avoid development on agricultural land and this is determined by economic growth, which prompts urbanization, expansion of commercial and industrial space, as well as transportation networks. Nevertheless, the dynamics of spatial growth should be continuously monitored by using, where possible, quantitative methods for an assessment of landscape quality and natural resources, including soils as a key element of sustainability (Hasse & Lathrop, 2003; Zhang et al., 2007).

Modelling is becoming an important tool in this context, since changes in rural areas, such as degradation and loss of biodiversity, usually proceed very slowly. However, they are often irreversible, and this is why models become crucial – even if their predictive power is sometimes limited, they can provide valuable insights into the development of trends caused by different policy scenarios and economic development etc. (Westhoek et al., 2006). The utility of models lies in their ability to detect possible conflicts that may arise as a result of implementing a given policy scenario affecting land use (Hilferink & Rietveld, 1999; Agarwal et al., 2001).

This study is aimed at assessing how land use change, and in particular the development of artificial surfaces, affected soil quality in Europe in 1990-2000. An additional objective, following a historical analysis of land use change and its impacts on soil resources, is to test the utility of System Dynamic modelling as a simple tool for predicting future claims that will consume agricultural land, in response to economic and population growth in the EU-27. The research presented here is based on harmonized European data for land use and soil (Heineke et al., 1998; Kirkby et al., 2004; Jones et al., 2005; EEA 2005; EUROSTAT, 2006), the thematic layers are derived trough pedotransfer functions, as well as on statistical information, which were integrated and analyzed using common GIS tools.

Results of this study are an outcome of the EU funded projects “LUMOCAP” and “SENSOR” dealing with modelling of land use changes and impacts.

1.1. SOIL CONTEXT OF LAND USE CHANGE

The intensity and direction of land use changes observed across the EU are directly related to a competition between different sectors, reflecting a specific demand for land – this demand displays a tremendous regional variability and is driven by the global macroeconomic situation, socio-economic characteristics of the regions, the rules of spatial planning, polices, as well as complex interactions between these factors and the physical properties of landscapes (Verburg & Chen, 2000). On a local landscape level, spatially explicit changes in land use are strongly linked to physical land suitability, defined as an ability to perform a given function (Alberti & Waddell, 2000; Wu & David, 2002; Verburg et al., 2004). It is commonly accepted that agriculture and forestry are among sectors which are most prominently contributing to the

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development and protection of landscapes and their functions – soil conservation is definitely an inherent condition of sustainability (Karlen et al., 1997). An excessive loss of agricultural land and forests can disturb the balance in ecosystems and prompt their degradation. A loss of the most productive agricultural soils and deforestation, in order to supply space for urban sprawl or for agricultural production, are good examples of detrimental changes affecting hydrology of watersheds and increasing the risk of flooding and erosion, (Houghton, 1999; Walling, 1999; Fohrer et al., 2001; Tang et al., 2005).

A great deal of research focuses on impacts of land use change on habitats and the relationships between landscape patterns and biodiversity (Savard et al., 2000; McKinney, 2002; Pauleit, 2005). There are also studies which explore consequences of land use change for soil functions (Drew, 1983; Bouma et al., 1998; Römkens et al., 1999; Conant et al., 2004; Boyd & Slaymaker, 2000).

From a sustainability perspective, it is sensible to postulate that soils rich in organic matter (OM) should be protected against urbanization, respecting OM's role in controlling biodiversity, its retention functions and stabilization of the soil's physical structure, as well as erosion control (Barrow, 1991).

Recently, there has been a new emphasis on soil's OM protection, since soils play a fundamental role as carbon sinks, thus their ability to accumulate carbon as a result of proper management can contribute to stripping and controlling CO_2 emissions to the atmosphere (Lal, 1997; Dumanski, 2004). There are estimates suggesting that in the last 150 years CO_2 emissions, generated by land use change were nearly half as much as the amount released from fossil fuels over this period (Houghton et al., 1983; Houghton, 1999).

Similarly, land of the best agricultural suitability should also be protected from urbanization in order to preserve its production function, although historically, settlement and growth of urban areas were often associated with land of high productivity and therefore choices for further expansion of urban fabric are sometimes limited and potentially conflicting with protection objectives (Imhoff et al., 2003; Hasse & Lathrop, 2003; Zhang et al., 2007).

Unfortunately, from a standpoint of urban development, an understanding of soil functions is often reduced to mechanical parameters, important for the foundations of structures, while other functions, such as ecological, buffering, retention and production are often ignored in development and planning strategies. Water retention capacity and hydrological systems can be greatly affected by land use change and spread of built up areas – this also includes the quality of water, which can decline as a consequence of urban runoff. High levels of heavy metals are found in surface waters in areas with a high percentage of impervious cover, therefore building on contaminated land is not only detrimental from a perspective of direct human exposure to a dust or food chain risk, but also includes off-site effects by carrying contaminated sediments and dissolved metals into streams (Klein, 1979; Sloane Richey et al., 1981; Paul; & Meyer, 2001; Sutherland & Tolosa; 2001; Turer et al., 2001).

Until recently, launching EU-wide studies on soil aspects of a land use change was

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exclusively limited to organizations which had an access to European data – most of it was restricted for an internal institutional use, according to respective proprietary rights, within public EU organizations. This was effectively changed in 2005 with a new policy of EU institutions, such as EUROSTAT, the European Environment Agency (EEA) and the Joint Research Centre (JRC), making some of their data sets available to the public. This includes CORINE land cover maps for 1990 and 2000, a soil map and EUROSTAT socio-economic data (Heineke 1998; Kirkby et al., 2004; EEA, 2005; EUROSTAT, 2006).

1.2. OVERVIEW OF LAND USE CHANGE ANALYSIS – APPROACHES AND PROBLEMS

Remote-sensing technology has been a primary source of reliable data characterizing land use change, allowing a spatial analysis of stocks and flows, by detecting even discrete changes in scales depending on image source and resolution. Changes occurring in small areas can be successfully monitored by aerial photography (Light 1983; Mason & Rüther, 1997). However, an analysis of a regional or global context requires an application of satellite imagery (Green et al., 1994; Lambin, 1996; Chen, 2001).

In Europe, the European Commission implemented the CORINE Programme (Co-ordination of Information on the Environment), which aimed at developing a land cover inventory (CLC). The programme generated two CLC databases for 1990 and 2000, as well as layer of changes CLC1990/2000 (EEA, 2005), giving an assessment of stocks and flows to be used for European and national-level environmental studies. A continuation of CORINE will provide a unique opportunity to monitor changes in a consistent way, which is a condition to understand the driving forces and processes that control changes (Bounfour & Lambin; 1999). Upgrading the time series of inventory of stocks and flows and land accounts enables us to asses the scale of changes and also helps to calibrate land use change models.

In Poland, there has been a considerable amount of research on calculating stocks and flows and driving forces of changing land functions within rural areas (Kaczmarek, 1988; Bański, 2001; Domański, 2001; Bański & Stola, 2002; Domański; 2002; Bański 2003; Wasilewski & Krukowski, 2004; Bański 2005; Stuczyński et al., 2006a). Spatially explicit examples of land use change analysis considering the quality of soil in urbanized areas include a regional analysis for Podlaskie in Poland (Stuczyński et al., 2006b).

In the assessment and modelling field, studies focusing on spatial patterns of land use in relation to a spatial distribution of biophysical features, as well as the variation of socio-economic environment are common (Braimoh & Vlek, 2004; Hietel et al., 2004; Verburg & Chen, 2000; Walsh et al., 2001; Wear & Bolstad, 1998).

A considerable part of contemporary research on land use issues concerns the use of tools to predict changes of space functions (Landis, 1994; Wegner 1994; Johnson & de la Barra, 1998; Engelen et. al., 1999; White & Engelen, 2000). These studies recognize drivers of land development, assuming that it is predictable and controlled by rules that can be parameterized and formalized in the form of algorithms.

Extensive research has focused on the dynamics of urban systems and their ecol-

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ogy, however, these complex processes have yet to be synthesized into one coherent modelling framework (Low et al., 1999; Alberti & Waddell, 2000). Openshaw (1995) expressed a concern that modelling efforts have often evolved separately, and isolated disciplinary approaches have not addressed the processes and variables that drive human and natural systems adequately.

The pioneering work on agricultural land use modelling, addressing crop choice, was proposed by von Thünen as early as in nineteen century (Dempsey, 1960). It was based on the principle of maximizing profits from production and took into account the distance from the markets (Crosier, 2001). Land suitability was assumed as even across the entire space, and markets were assumed to be isolated, not influenced by external factors. Moreover it was also assumed that farmers act in a rational way, making all efforts to maximize profits from their land (Dunn, 1954; Alonso, 1964).

Land use change simulation models retrieve the mechanisms and drivers controlling land development in a dynamic way, considering the feedback between drivers affecting modelling outputs (Engelen et al., 1999; Agarwal et al., 2001). Models are operating either on a regional or a local level, where administrative boundaries are used to delineate modelling units – e.g. different NUTS units. This approach allows for an integration of statistical data that are collected for different administrative units into a single model. However, a further step is disaggregating modelling outputs into a grid level to demonstrate the spatial distribution of changes.

A key issue in modelling is to recognize various interactions between the drivers controlling spatial development. Land suitability, which is specific for different alternative functions of a space, and the availability of a given spot for these functions, both in term of physical characteristics and the rules of spatial planning, are crucial for predicting future land use on a local level (Wilson, 1998; Engelen et al., 1999).

One of the main problems is to construct models that are able to depict regional specifics efficiently – it is well established that the pattern of changes may vary greatly between regions, as they can be very diverse in terms of economic and natural conditions. Clustering is one of the methods used to group regions of potentially similar behaviour (Nowicki et al., 2007). Descriptive statistics can be a first step in an analysis of land use changes as a function of different socio-economic and environmental parameters, prior to the development of models. Multivariate regressions can provide coefficients used in more complex models and help in defining significant drivers (indicators) of a land use change (Verburg et al., 2004). A good example is the application of a stepwise logistic regression to retrieve the relationships between land uses and the driving factors leading to change – the model predicts the probability for a grid cell of the occurrence of the given land use type as a function of variables characterizing the driving factors (Verburg et al., 2004). Although Alberti and Waddell (2000) are critical about stochastic models applied in land use change analysis, pointing out that a process-based approach is the only relevant choice for an adequate depiction of the links between human-induced causes and ecological effects. In their view stochastic transition models cannot relate causes and effects, nor can they incorporate feedback

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mechanisms and acquire a dynamic property. Certainly this is true for spatially explicit analysis driven by biophysical features of terrain, and does not necessarily apply to calculating land claims on a regional level.

There are studies on land use change that point out the necessity of considering landscape biophysical attributes, as they interact with a decision-making process affecting change rate and spatial appearance (Bürgi et al., 2004). Many land use modellers have based their models on theories, concepts and modelling techniques originating from landscape ecology (Baker and Mladenoff 1999; Grimm, 1999; Guisan & Zimmermann 2000; Milne 1998; Verburg et al., 1999; Voinov et al., 1999). The major difference between ecological models and land use models is the dominancy of human decision-making processes in land use models.

The possibility of a combined analysis of landscapes, recognizing decision-making processes and structures, has been explored in many studies linking natural and social systems (Adger, 2000; Brown et al., 2005; Holling & Sanderson, 1996; Overmars & Verburg, 2005; Rindfuss et al., 2004; Scoones, 1999). However, as pointed by Verburg (2006), these approaches are far from satisfactory implementation, which remains a major challenge.

Land use modelling essentially deals with two levels of aggregation and represents two different approaches: the first is often called top-down aggregated analysis, and explains land use claims on a macro or regional level within boundaries of administrative units, such as NUTS. The second, called the bottom-up approach, addresses spatial distribution of claims by retrieving change on a pixel level. Depending on the context, the macro level is mainly driven by exogenous factors, which are not directly linked to biophysical properties of a land – e.g. claims for urban and industrial/commercial land are purely driven by socio-economic variables such as GDP, demography and employment in a region or a country, depending on the resolution of the modelling exercise. Claims for artificial surfaces on a regional level very strongly depend on the attractiveness and economic strength of a region, for which GDP level and growth may be good proxies, but not exclusively so. In the case of agricultural land use patterns, local factors and land-related parameters, such as suitability for growing certain crops also play a role, which interacts with such exogenous (relative to land properties) factors such as market demand and marginal profits, which are basic parameters of decision-making processes on a farm level, defining crop choice and land management pattern.

Examples of top-down type models include the following applications: Environment Explorer (de Nijs et al., 2004; White & Engelen, 2000), CLUE (Verburg et al. 2002) and the Land Transformation Model (Pijanowski et al., 2002). Bottom-up models focus on the local level and local factors and decisions driving the change – the output therefore is a sum of local changes, as they are influenced by local and regional conditions. Driving factors of land use change are also studied in a similar manner – following either a top-down or a bottom-up approach. A number of studies focussed on finding causes of land use change – triggering variables, and variables regulating

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the rate of changes (Geist & Lambin 2002, 2004; Rudel 2005).

It was postulated by Bürgi et al. (2004) that the top-down approach helps to identify precursors of land use change operating on a macro level, whereas bottom-up analysis, dealing with biophysical attributes of a landscape, leads to the identification of attractors of change. In this sense attractors are inherent properties of a landscape that attract or prohibit change into a certain direction – e.g. wetlands will not likely allow urbanization, and theoretically, strong soil contamination should also prohibit development. Precursors are factors that cause the change – e.g. a strong increase of GDP and population growth will create pressure triggering urbanization. In other words, biophysical features control where change in a land use appears in space, whereas socio-economic variables mainly control the rate of change and the size of demand for particular land use functions (Veldkamp & Lambin, 2001). It needs to be pointed out that non-spatial models of land use change only deal with the rate of land use change (Stéphenne & Lambin 2001). However, for the sake of clarity, it is important to mention that even in most of the spatially explicit land use models both types of processes (top-down and bottom-up) are addressed, but often an assumption is made about the dominancy of either the processes acting at the macro-level, constraining the spatial processes, or the emergence of aggregate change through the local (spatial) processes (Verburg, 2006).

Verburg (2006) stresses the importance of the fact that a purely bottom-up or top-down hierarchy is insufficient in most cases. Local decisions can be influenced by feedback from the aggregate level - e.g., an economically optimal land use choice at the farm level may no longer be optimal if many farmers in a region make the same decision leading to market saturation. Regional land requirements may not be fulfilled due to land scarcity or a conflict with local traditions. A typical example of a land use system that is determined by both bottom-up and top-down processes is the shifting cultivation system. Land demand from households, communities and markets determines the need for agricultural produce of a region or community. Local labour availability and land resources are an important constraint to expanding the agricultural area (Castella et al.; 2005). Furthermore, because of a lack of external inputs of fertilizers soil fertility declines and after some years agricultural plots need to be abandoned and left fallow in order to let the soil recover. In this system, the spatial dynamics are largely steered by local social and biophysical processes. The rate of land use change is jointly determined by local resources and processes at higher levels of organization, potentially conflicting with the sustainable use of the resources (van Noordwijk 2002).

The distribution of claims for different land use functions into a grid is commonly done by tools such as CLUE-s and cellular automata (Verburg et al., 2002; White & Engelen, 1997; White et al., 1997). Regardless of the type of tool, a key challenge is to incorporate proper rules into the grid-based model, taking into account neighbourhood effects, zoning and protection regulations, suitability and accessibility for a given function (White & Engelen, 2000). Some models integrate a process of land use change as driven by consumer and supplier perspective and surplus impact on land prices (Alberti

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& Waddell, 2000).

The top-down approach is adequate for this study, as the analysis of land use change processes is not run on a landscape level, but within regional boundaries and focuses on an area demand for different functions, using assumptions of system behaviour learned from the past. Spatially explicit modelling would require incorporation of a bottom-up approach, as biophysical features of space have a dominant impact on where change takes place.

There is a clear tendency observed in modelling in recent years to combine different models that are suitable for a given purpose in a wider modelling and very complex frameworks, which allows for a synergy and better capturing of processes – examples include econometric tools such as NEMESIS (Fougeyrollas et al., 2001) which are incorporated into land use change modelling and impact assessment under SENSOR, the EU funded project. However, Pickett et al. (1994) point out that linking models in an additive fashion may not adequately address system behaviour because interactions between human and environmental processes occur at levels that are not represented.

In SCENAR 2020, an initiative launched by the European Commission to model changes in the EU-25 rural areas, three economic models: LEITAP, ESIM, CAPRI and an ecological-environmental based model framework (IMAGE), as well as a land use allocation model (CLUEs) were combined (Nowicki et al., 2007), which created a very sophisticated modelling chain. Such modelling frameworks can be very robust, but they are usually not transparent and not easily accessible for the research community or for users as learning and simulation tools.

2. MATERIALS AND METHODS

2.1. DATA SOURCES

2.1.1.Non-spatial variables and indicators

The EUROSTAT database was used as a main data source for characterizing NUTS-2 and 3 for the analysis of land use change within the EU-25. All essential parameters were collected at the largest possible temporal resolution to study their trends - data from 1995/1997 up to 2005 were obtained for the EU-25 (Eurostat, 2004). As already mentioned, a combination of NUTS-2 and NUTS-3 (NUTS-x) regions was chosen to arrive with units of a more or less similar size in different European countries. The NUTS-x grid is accepted as a feasible approach for European-scale analysis, ensuring a proper spatial resolution of statistical variables, although at the expense of many important parameters which are available for NUTS-2 units but not for NUTS-3. In consequence, a complete set of EUROSTAT data for the network of NUTS-x regions consisted only of less than 20 independent variables, listed in Table 4 – other indicators had more or less significant gaps. The social, eco-

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nomic and environmental data characterizing the Silesian region was collected at resolution of NUTS-5 from the Bank of Regional Data (GUS, 2006). The Bank of Regional Data provided variables for NUTS-5 units (gmina, or local authority level) for such categories as demography, labour market, agriculture, forestry, transport, environment protection, waste management, commerce, tourism, education, healthcare, welfare, budget, investments, etc. The GUS regional data generally covers the period from 1995 to 2005. Statistical variables were often normalized to 100 ha or 1000 inhabitants, depending on the type of the variable – to enable comparisons between NUTS units of different area size. Biophysical conditions in NUTS-5 regions were represented by Land Quality Index (LQI), which is an aggregated parameter, describing land productivity and is derived from soil maps, digital terrain models (slope) and climate data (Witek & Górski, 1977). Additionally, a soil erosion index (Witek & Górski, 1977) and soil contamination with metals ($mg \cdot kg^{-1}$) were calculated for each NUTS-5 unit as weighted means, using unit area as the weighing factor.

2.1.2 Soil and land quality data

The assessment of land suitability (LS) for crop production was modelled for Europe, accounting for components that control yields – climate and water balance. Dry mass production in the model (DM) is restricted by soil available water, driven by precipitation, evapotrasnpiration and water retention characteristics of soil cover. Evapotranspiration in the model is calculated according to the FAO approach (Allen et al., 2000). Yields are also restricted by temperature and terrain conditions (slope) – a numerical solution of LS calculation followed the methodology tested in a previous work (Łopatka & Stuczyński, 2007). The equation relating LS to dry mass production, temperature and slope is given below.

$$LS = \left(1 - \frac{slope}{90}\right)^{\alpha} \cdot \left(\frac{T_{mean}}{T_{opt}} e^{1-\frac{T_{mean}}{T_{opt}}}\right)^{\beta} \cdot \left(\frac{DM}{DM_{\max}}\right)^{\gamma}$$

The first term in the LS equation is a function which produces a value of 1 if the slope is equal 0°, as there are no terrain constrains for crop growth. For a slope of 90°, it equals 0 and for intermediate slopes, the LS value depends on the á coefficient. The second term in the LS equation characterizes the impact of temperature on yields. This function is of a skewed bell shape – its maximum value is 1 – reached at a temperature optimal for a plant growth (T_{opt}), whereas the value of 0 is reached at 0°C, which is a temperature were growth processes are stopped. The third term represents the ratio between the biomass produced in a vegetation season (DM) and the biomass that could be produced in optimal conditions - if there is no water stress this term would equal 1. There is an assumption that the dry matter produced is proportional to the amount of evapotranspiration (de Wit, 1958). Within this term there is a water balance calculation included, relating the stage of crop development to the

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water available to plants in the soil, the amount of precipitation and actual evapotransipration (Thornthwaite, 1955). Numerical solutions were done following Donker's scheme (Donker, 1987).

Climate data for the model was obtained from The Intergovernmental Panel on Climate Change (IPCC), a soil map in 1:1 M scale was used for modelling water balance throughout the vegetation season. The climate data represented 30 year monthly means and this determined a calculation interval. The calibration of the model by a multiple linear regression was based on the EUROSTAT yield data for NUTS-2 regions. In order to compare output values with observed yields, a correction was introduced by accounting for a reduction of potential biomass caused by a level of management and inputs, which vary greatly across Europe – the less technologically and economically advanced the region is, the larger the discrepancy between observed and potential yields. To account for this impact, GDP was used as a proxy of management level. A calibration of the model after correcting for GDP allowed for explanation of over 70% of yield variability observed in NUTS-2 regions.

Land suitability (LS) used in this study is derived from the above model, run for soft wheat. LS is a continuous 1 km grid layer, expressing potential productivity in a 100 point scale, indicating to what extent a maximum yield is constrained in a given location. Outputs were arbitrarily grouped into 3 LS classes: low (<35), medium (35-70) and high (>70).

Soil quality spatial layers included: erosion assessment obtained from Pan-European Soil Erosion Risk Assessment (Kirkby et al., 2004), carbon generated by pedotransfer functions (Jones et al., 2005), water retention capacity generated for a 1 m profile based on the texture information taken from the European Soil Database Version 1.0 – ESDB (Heineke, 1998). These layers are available in a 1 km grid resolution. Soil organic carbon content was grouped into four classes to demonstrate a distribution of low (<1%), medium (1-2%), high (2-3.5%) and very high (>3.5) carbon soils. Soil water erosion assessment was grouped into four classes of risk expressing potential soil loss: very low (<1 t · ha^{-1}), low (1-5 t · ha^{-1}), medium high (5-10 t · ha^{-1}), and very high (>10 t · ha^{-1}).

Water retention is directly linked to the texture of the soil profile. Data characterizing the spatial distribution of water retention, defined as total available water (pF values 2-4.2) was generated from ESDB in a scale of 1:1 M – parameters used for pedo-transfer in order to derive water retention profile textures were taken from Wösten (1999). Water retention expressed as the water available for plants, at a field capacity, for a 1 m soil profile was grouped into three retention classes: low (<190 mm), medium (190-230 mm) and high (>230 mm).

Soil data for Silesia was represented by continuous grid layers characterizing content and spatial distribution of lead, zinc, and cadmium in a top layer of agricultural soils. Layers were derived through interpolation of measurements from 5000 geo-

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referenced sampling points (Terelak et al., 1997).

2.1.3. Other biophysical and landscape data

Landscape metrics were calculated for the EU-25 NUTS-x regions as indicators of landscape heterogeneity and pattern. High landscape diversity is considered to be indicative of land buffering capacity and resistance to various anthropogenic pressures (Antrop, 2004). Four landscape metrics were calculated by using Fragstats software and CORINE land cover as the data source for both 1990 and 2000 – Patch Density, Edge Density, Shannon Diversity Index and Interspersion and Juxtaposition Index.

Patch density (PD) is a number of patches in the landscape divided by the total landscape area. Edge density is a sum of the length of all edges divided by the landscape area. Shannon Diversity Index (SHDI) represents diversity metrics being based on two components: the number of different patch types and the proportional area distribution among patch types. Interspersion and Juxtaposition Index (IJI) quantifies the landscape's spatial configuration (McGarigal and Marks, 1995; European Commission, 2000). Landscape diversity indicators reflect different features and patterns of landscapes, but they are usually strongly correlated with each other.

2.2. THE APPROACH TO LAND USE CHANGE ASSESSMENT

As discussed in the review of approaches to land use analysis, it is essential to understand how changes in land use correlate with socio-economic and environmental indicators across the EU, as well as within regions. This analysis is thought to verify the input for land use change modelling, and to assess weights assigned to different drivers of this process. It is evident that certain settings of socio-economic conditions, defining regional specifics, predispose some regions to attract investments, thus causing a stronger pressure on agricultural and other areas, which are being transformed for urban or industrial and commercial functions. The analysis of land use change across Europe between 1990-2000 conducted here recognizes the physiogeographic, economic and social variability of the European regions. Explanatory analysis of changes in land use, as a function of various parameters, such as gross domestic product (GDP), demography and employment, was conducted for five European clusters, grouping regions of more or less homogeneous socio-economic and environmental characteristics and patterns. These different patterns allow a delineation of distinct groups of regions, representing a similar behaviour and characteristics. They form more or less homogenous clusters of similar internal properties, which are distinct from other clusters in terms of economic and social pattern as represented by a population size, GDP level and growth rates, as well as different structure of land use and its evolution. Combining regions into geographically and economically similar clusters, it is helpful to identify differences in management and policy instruments needed in order to promote their economic, social and environmen-

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tal coherence.

Flows in land use functions are also analyzed in the context of soil and land quality, to evaluate impacts on soil functions through selected indicators, specifically to see how soil sealing (development of artificial surfaces) relates to a distribution of soil organic matter, water retention, soil erosion and land suitability for crops. Additionally, for Silesia, an industrial region of Poland for which finer resolution land use and soil contamination data were accessible, land use conversion is assessed in the context of soil contamination status. An EU-level analysis was conducted with a combination of NUTS-2 and 3 regions of similar size, using a set of EUROSTAT statistical survey data – combining NUTS-2 and NUTS-3 into NUTS-x grid was decided to cover the EU territory with a network of regions of a similar size, which is better for the quality and resolution of outputs.

2.3. THE APPROACH TO MODELLING

As demonstrated in the introduction, many robust, but sophisticated econometric and ecological models and frameworks have been developed for land use change studies. However, their availability and practical usage is limited to advanced expert groups. A development of system dynamic modelling utilizing graphic representation of stocks and flows of the system's variables is a crucial step to enable non-modeller experts to analyze complex systems by bringing them into simple structures, while still accounting for their complexity (Checkland, 2000; Haraldsson, 2005). The underlying justification for this effort is an assumption that it is not always necessary to invest in building very sophisticated models if relevant answers can be obtained by using less exhaustive concepts and modelling frameworks (Haraldsson, 2003). Keeping in mind the new challenges in policy assessment on a local and regional level, there is an urgent need to investigate new possibilities for modelling, which allow for a scientifically acceptable but a quick analysis of system behaviour without the need for a large investment in computing resources, data and labour. User-friendly tools for designing models such as VENSIM or STELLA are currently emerging in the natural sciences (Haraldsson, 2005) – these solutions aid the graphical visualization of systems, and enable computing and calibration of models without the necessity of an extensive programming expertise. Concepts and thoughts reflecting mental models are visualized as casual loop diagrams (CLD) and stock and flow diagrams (SFD), showing the relationship between system variables and allowing the calculation of rates of change. CLDs can help to capture the knowledge and system understanding communicated by experts, brought together as a modelling group. These approaches provide a great advantage for researchers, experts and policy makers, by enabling them to translate extensive knowledge, including qualitative elements, into system modelling (Haraldsson, 2005).

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2.4. CLUSTER AND STATISTICAL ANALYSIS

Cluster analysis was performed in order to classify the EU-25 regions into relatively homogenous groups which would represent similar environmental, socio-economic, agricultural and geographical profiles. Cluster analysis was performed by K-means for NUTS-x. The variables used in cluster analysis were subjectively pre-selected, based on expert knowledge, to cover key social, environmental and economic issues required for policy assessment (SEC, 2005). The type of variables selected was designed to capture the complexity of natural and socio-economic conditions in NUTS-x units analysed. Several attempts of a variable selection were made to arrive with the kind and number of clusters that could be interpreted as distinct from a socio-economic and environmental perspective. The method for maximising distances between clusters was based on a preliminary selection of clusters centres. In each iteration of this clustering algorithm, positions of centres are changed in order to maximise distances between clusters and to reduce the variability within a particular cluster.

The above defnition generated five distinct European sub-regions and areas in the Silesian test region, representing similar social, economic and environmental conditions. A correlation analysis between the preliminary set of input variables was performed to exclude less important variables that were intercorrelated with indicators, essential for land use change analysis. Variables used to distinguish EU-25 clusters included: length of the vegetative period (days), mean precipitation in vegetative period IV-X (mm), unemployment rate (%), gross domestic product (GDP/inhabitant), population density (inhabitants/km^2), economically active population (% total population), crude birth rate (number/1000 inhabitants), crude death rate (number/1000 inhabitants), employment in industry (% economically active population), employment in agriculture (% economically active population), agricultural land area (%). A trend analysis was performed within clusters to assess changes in population density, GDP and employment structure within these homogenous areas throughout Europe and test regions. The timeframe for this analysis depended on available statistics - either EUROSTAT, or the national census. The analysis of relationships was performed using Statistica 6.0 software. Pearson's correlation coefficients were calculated to evaluate the significance of relationships between land use changes and biophysical and socio-economic variables. Stepwise regression models were generated to explain observed land use flows in 1990–2000 for the EU-25.

Taking into consideration a different set of available NUTS-5 variables, the following parameters were used for clustering in Silesia: mean farm size (ha), land quality index, population density (residents/km^2), employment in the industrial sector (%), agricultural land area (%), total number of businesses (number/10000 residents), total budget income (Polish zloty/resident), farms with income from agricultural activity only (%), mean zinc content in soil as pollution indicator (mg/kg).

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2.5. LAND USE CHANGE ANALYSIS

Land use change analysis for the EU-25 was based on CORINE layer of changes obtained from EEA (2005) – this was the 2005 version of the revised data characterizing land use conversions between 1990 and 2000. The CORINE land cover database provides information on land use types grouped into different levels of aggregation. An analysis of land use flows across different categories of soil properties (erosion, OM content, water retention capacity and land suitability) was conducted using aggregated land use classes such as: artificial areas, arable land, pasture land, forest and semi-natural areas. A general description of land use change within clusters was based on a more detailed land use classification covering selected classes of CORINE level 1. Theoretically, hundreds of different combinations of land use flows are possible, depending on the classification level in CORINE (EEA, 2006a), and this is the practical reason behind a more synthetic approach used in the analysis. Considering that the generalization of soil layers was at a 1 km grid, an assessment of flows of agricultural land in relation to soil characteristics was conducted for combined classes. A more detailed analysis of flows relative to the distribution of soil properties would introduce more uncertainty produced by overlaying small size patches of diverse land use classes on generalized layers of soil properties. GIS software (ArcGis 9.2) was used to process land use and soil spatial data.

As the CORINE land use change layer for Silesia was very generalized and relatively few changes were detected, it was decided that the data were too coarse and did not permit a realistic analysis of agricultural land conversion into other functions, relative to soil contamination pattern. Therefore a 30 m resolution layer of changes was used, derived for two periods: the mid eighties and 2003. The reference data for the eighties came from different sources including LANDSAT images and topographical maps. The 2003 data was obtained from commercial sources and the classification was based on IRS images merged with LANDSAT-7 TM. Prior to the analysis of change, layers were brought into the same resolution, and intense processing was done to eliminate artefacts such as small changes and linear features representing inaccuracies of data and not real changes. A lack of well-defined time period for land use change analysis based on these sources did not allow a more comprehensive analysis of change as a function of socio-economic drivers. Besides an uncertain time reference, statistical data at NUTS-5 level is not available for the period before 1995. Therefore, the analysis was limited to learn how long-term changes in land use are related to soil contamination.

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2.6. THE APPROACH TO THE ASSESSMENT OF THE INTENSITY OF LAND USE CHANGES CONSIDERING SPATIAL PATTERN OF SOIL PROPERTIES INDICATIVE OF SOIL FUNCTIONS AND DEGRADATION RISK – – TRANSITION INDEX

Land resource impact indicators (LRI) of urban sprawl include a number of different parameters reflecting the impact of development on critical land resources (Hasse & Lathrop, 2003). However, none of them, except prime farmland consumption, addresses the impact on critical soil resources. In order to assess the scale of development consuming best quality soils or growth which could alter consequences of degradation (e.g., erosion and contamination), a transition index was developed to reflect the intensity of land use flows in the context of soil quality.

Looking at land use stocks and flows occurring on soils belonging to different property classes (e.g. high OM, high erosion risk), it is difficult to make a straightforward assessment whether the observed land use change is equally distributed among classes distinguished, or is it non-proportional and consumes areas of certain characteristics, less or more intensely, as compared to a general pattern of a given soil parameter. Difficulties arise from the fact that the contribution of e.g. high organic matter soils to the total soil cover may vary greatly between regions – therefore the size of change on soils of certain characteristics is not a good indicator of whether these soils are preferentially taken for instance by urbanization or forestry. Preferential flows occur when a certain soil type (characteristics) represents a larger share in the changed land as compared to the share of this type in the general soil cover. Taking an example of OM, as a soil quality indicator, the area of high OM soils in the region may be small, but intensity of the transition may be high if more high OM soils are converted into artificial surfaces than is expected from the percentage share of high OM soils in the total soil cover. Thus, calculating a ratio between the share of a given soil type (class) within the changed area and the share of this class in the total soil cover of agricultural land (arable or pasture) provides a clear indication of the intensity of transition on the soil type considered.

This simple conversion index is proposed to characterize the intensity of transition of agricultural land taking place on different soils, classified according to the ranges of land suitability, organic matter content, water retention capacity and erosion risk.

Interpreting the transition index is straightforward – for example, an index value of 2 for a flow on a given soil class (e.g. high OM content) means that within changed land the share of this class is twice as high as in the entire soil cover. Therefore, the intensity of high OM soils consumption is much larger than can be expected from a structural pattern of soil OM. In contrast, if, for instance, the percentage share of high OM soils within arable land changed into built-up areas is considerably smaller than 1 (e.g. 0.5), it means that these soils are protected from expansion of artificial surfaces - in this example the share of high OM soils is two times smaller within the changed area, relative to their contribution to the total cover.

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Transition indexes were calculated for basic land use flows for different land suitability classes, soil organic matter content classes, erosion risk classes, and water retention capacity for the EU-25. Additionally, a case study area of the Silesia region of Poland was included in the analysis, to evaluate intensity of agricultural land flows into forest and artificial areas, across different soil heavy metal contamination levels.

The interpretation of transition index values is arbitrary - values in a range of 0.7 to 1.3 are interpreted as indicative of non-preferential flows consuming soils representing a given range of parameters. Such a wide range of flows considered as non-preferential, relatively to e.g. high erosion or high OM soils, is necessary to account for the uncertainty of change analysis, resulting from generalization and different resolutions of thematic layers.

3. RESULTS AND DISCUSSION

3.1. TRENDS OF LAND USE CHANGES IN EUROPEAN CLUSTERS

One of the major constraints in spatial analysis of land use change, in relation to other parameters characterizing landscapes, is the quality of mapping and a number of uncertainties involved in cartographic materials (Cousins, 2001). In consequence, there may be significant discrepancies between topographical maps and the ground truth, particularly in areas of fast transition occurring in urban and suburban zones. Remarkable changes, which are often not depicted on maps, also appear on agricultural land taken by forestry. Also land cover maps generated by the classification of satellite images contain errors, and their correctness is assessed to be between 70-80% (EEA, 2006b). This is an important constraint that must also be borne in mind in the context of this study, since materials of different scales and methodological frameworks were combined together to analyze land use changes by recognizing environmental and socio-economic characteristics of areas converting into other functions.The contribution of main land cover classes in the EU is summarized in Table 1 (EEA, 2006a).

There were no remarkable changes of agricultural land area observed in 1990–2000 if we take the EU-25 as a whole. Agricultural land contribution to the total area was stable over the entire decade and came to approximately 46 %. Similarly, the share or arable land did not change either and covered about 24% of land in 1990 and 2000. It needs to be noted that the significant difference in areas of forests, wetland and water bodies between 1990–2000 is due to the fact that CORINE 1990 did not cover Sweden and several islands in southern Europe (EEA, 2006a). Forests and semi-natural areas cover almost 45% of total EU-25 area. The area of artificial land cover has increased since 1990 – presently artificial areas cover 4% of EU-25 territory. Focusing the analysis grouped into clusters shows a more detailed and cluster-specific pattern. The description and land use trends in these clusters is discussed further.

Spatial distribution of five clusters, grouping similar European regions, is shown on the map (Figure 1). Table 2 demonstrates standardized means of input variables into

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Table 1

The comparison of land cover class distribution in EU-25 countries between 1990 and 2000

Land use type	Area (ha)		Area (%)	
	1990	**2000**	**1990**	**2000**
Artificial areas	12861061.6	15946143.8	3.2	4.0
Urban fabric	9889010.6	11847806.3	2.5	3.0
Industrial, commercial and transport units	1695390.2	2293525.0	0.4	0.6
Agricultural areas	182481409.7	184179981.3	45.9	46.4
Arable land	94756367.9	97376800.0	23.9	24.5
Pastures	33931560.3	33426881.3	8.5	8.4
Forest and semi- natural areas	144095863.4	178013581.3	36.3	44.8
Wetland	3618883.2	8281268.8	0.9	2.1
Water bodies	6274322.4	10258937.5	1.6	2.6
Total area*	349331540.3	396679912.5	100.0	100.0

* Total EU-25 area covered by CORINE land use layer; land use data generated from CLC 1990 and 2000

each cluster. These means are indicative of factors deciding an allocation of NUTS-x regions into a given cluster. Key parameters instrumental for interpretation of each cluster are bolded (Table 2).

These standardized means can be used for comparisons of different variables between clusters and their relative importance for the definition of a given cluster. For example, a value of -1.38 for GDP in cluster 2, which is the lowest among all clusters, indicates that NUTS-x regions belonging to this group demonstrate the lowest GDP relative to other clusters. Similarly, a value of -0.72 for crude birth rate in cluster 1, being the lowest among all clusters, indicates that regions within this group are facing serious demographic problems, which was the main factor behind classifying these regions into one group. It is important to note that there are cases where regions of similar socio-economic trends, but different geographic location are clustered together – cluster 1 is an example of grouping together regions in Central and Eastern Europe and few regions in Portugal, mainly due to their rural socio-economic character.

Cluster description:
Cluster 1 – Industrial, economically and socially weak
Cluster 2 – Rural, economically and socially weak
Cluster 3 – Southern, economically and socially weak
Cluster 4 – Western, economically strong and socially balanced
Cluster 5 – Economically and socially strong, urban, non-industrial and non-agricultural.

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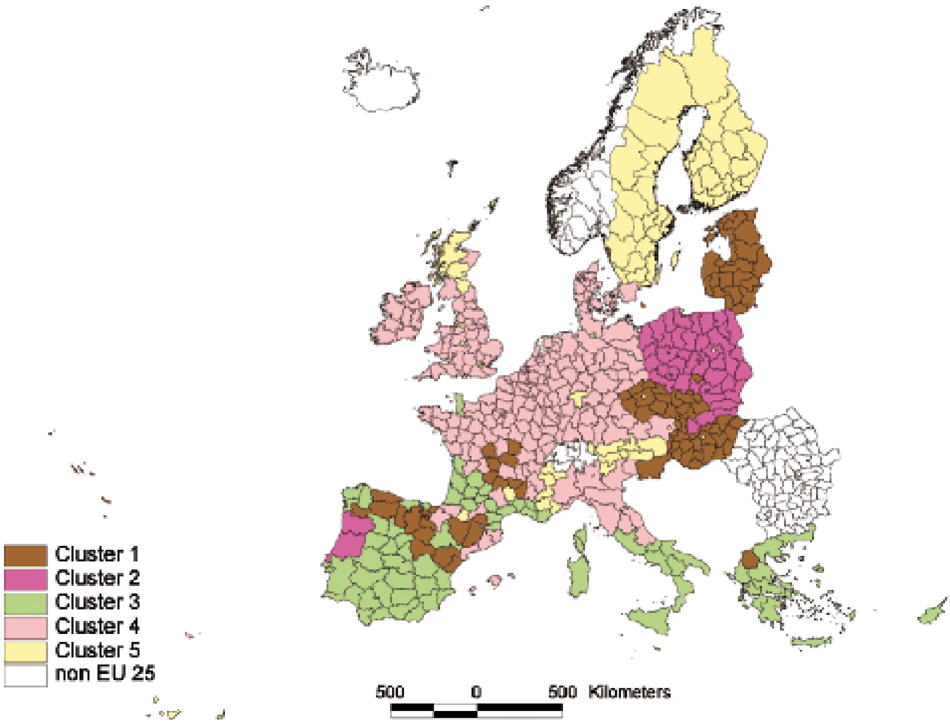

Figure 1. Spatial distribution of NUTS-x within 5 clusters

Cluster 1 covers 15.05 % of total EU-25 area and is comprised of 92 NUTS-x (Table 3) - mostly Czech, Hungarian, northern Spanish, all NUTS of Baltic countries and industrial regions in southern Poland, Slovakia and a few regions in France and northern Spain (Figure 1). This group of regions represents industrial and post-industrial character, as indicated by the share of the population employed in industry – on average 28.5% of the economically active population (Table 4). The unemployment rate slightly exceeds the mean for the EU-25 NUTS-x regions. It is the only cluster with a negative natural population growth, calculated as a difference between crude birth rate and crude death rate. A strong negative trend of population density was observed in the 1995–1999 period, which is indicative of emigration. However, since 2000 there is a considerable increase of population density (Figure 2). Negative natural population growth has been compensated by inflow of migrations in recent years. Gross domestic product (GDP) is low, approx. EUR 9000 per inhabitant being less than half the mean GDP calculated for all EU NUTS-x – EUR 18627 (Table 4). However, GDP growth rate is relatively high – 9.23% (Figure 3, Table 5). The most pronounced land use change within this cluster, between 1990 and 2000, was the conversion of relatively large areas of arable land into pastures, leading to a net gain of 0.31%,

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Table 2

Standardized means of input variables in cluster analysis within NUTS-x of EU 25 countries

Input variables*	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Length of vegetative period (days)	-0.36	-0.52	**1.54**	0.13	**-1.01**
Mean precipitation in vegetative period IV-X (mm)	0.01	-0.11	**-0.95**	0.24	**0.34**
Unemployment rate (%)	-0.02	**2.08**	0.43	-0.50	-0.30
Gross domestic product (GDP) (Euro per inhabitant)	**-0.94**	**-1.38**	-0.29	**0.52**	**0.85**
Population density (inhabitants/km^2)	-0.13	-0.19	-0.17	-0.11	0.67
Economically active population (% total population)	-0.21	0.10	**-0.99**	0.22	**0.58**
Crude birth rate (number/1000 inhabitants)	**-0.72**	-0.25	-0.28	0.50	0.05
Crude death rate (number/1000 inhabitants)	**0.74**	-0.29	-0.04	-0.32	0.08
Employment in industry (% economically active population)	**0.85**	0.22	**-0.53**	-0.01	-0.59
Agricultural Land Area (%)	0.08	0.47	-0.10	**0.57**	**-1.58**
Employed in agriculture (% economically active population)	-0.27	**1.64**	0.43	-0.16	-0.56

*Input variables taken from Eurostat (2006)

which is a positive trend from the soil conservation standpoint (Table 6). A net flow of agricultural land within this cluster into forests is half the average transition in the EU-25 (0.09 and 0.20% of the total area, respectively). The conversion of agricultural areas into artificial surfaces is again half that of the EU-25 mean (0.09% vs. 0.20%) and is equally distributed within urban areas, industrial/commercial and mine/dump/construction sites.

Cluster 2 consists of 42 NUTS-x regions, covering almost 10% of the EU-25 territory (Table 3). This cluster comprises most of Poland, a part of Slovakia and two

Table 3

Total area and number of NUTS-x in clusters within EU-25

	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**EU 25**
Area (ha)	59932604.0	38407512.0	74104558.3	128514914.6	96319708.6	397279297.5
Area (%)	15.09	9.67	18.65	32.35	24.24	100
Number of NUTS-x	92	42	73	186	80	273

Areas size calculated based on CLC 2000 and NUTS-x grid

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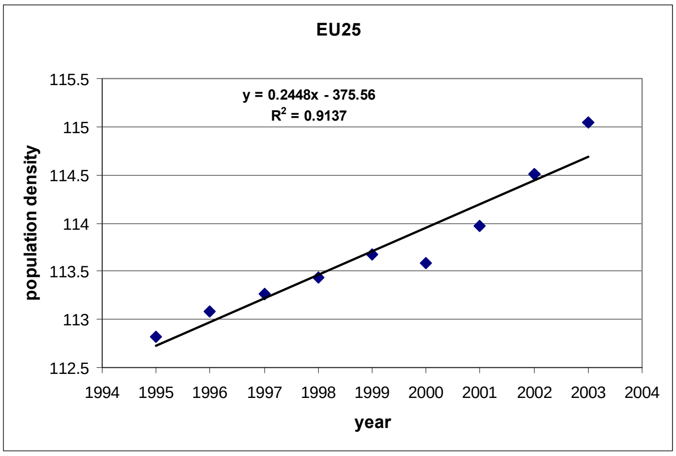

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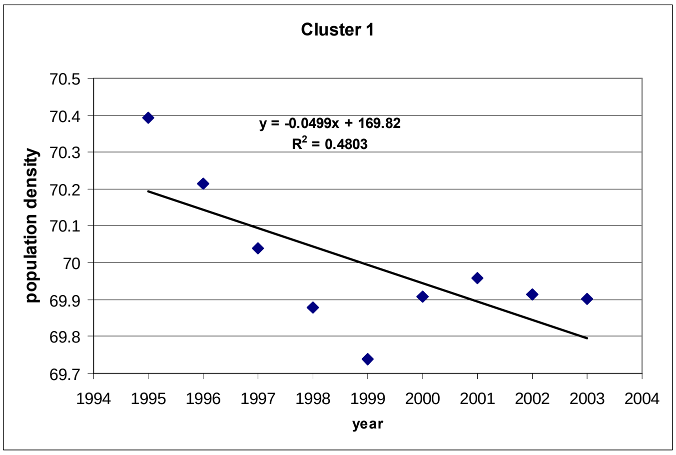

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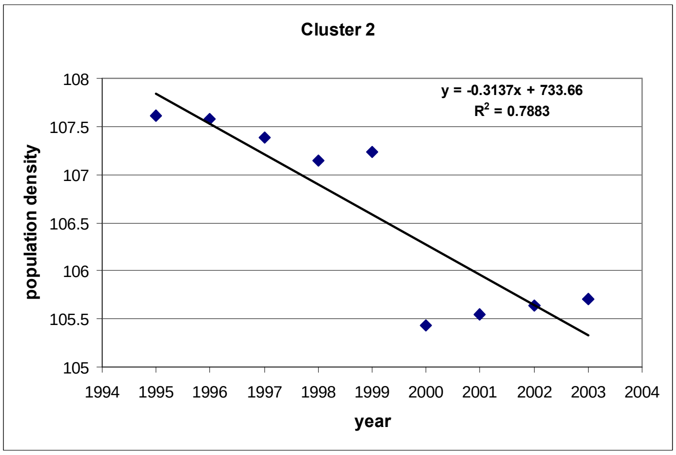

Figure 2 a, b, c. Temporal trends of population density in 5 clusters and EU-25 average NUTS-x (calculated based on Eurostat data, 2006)

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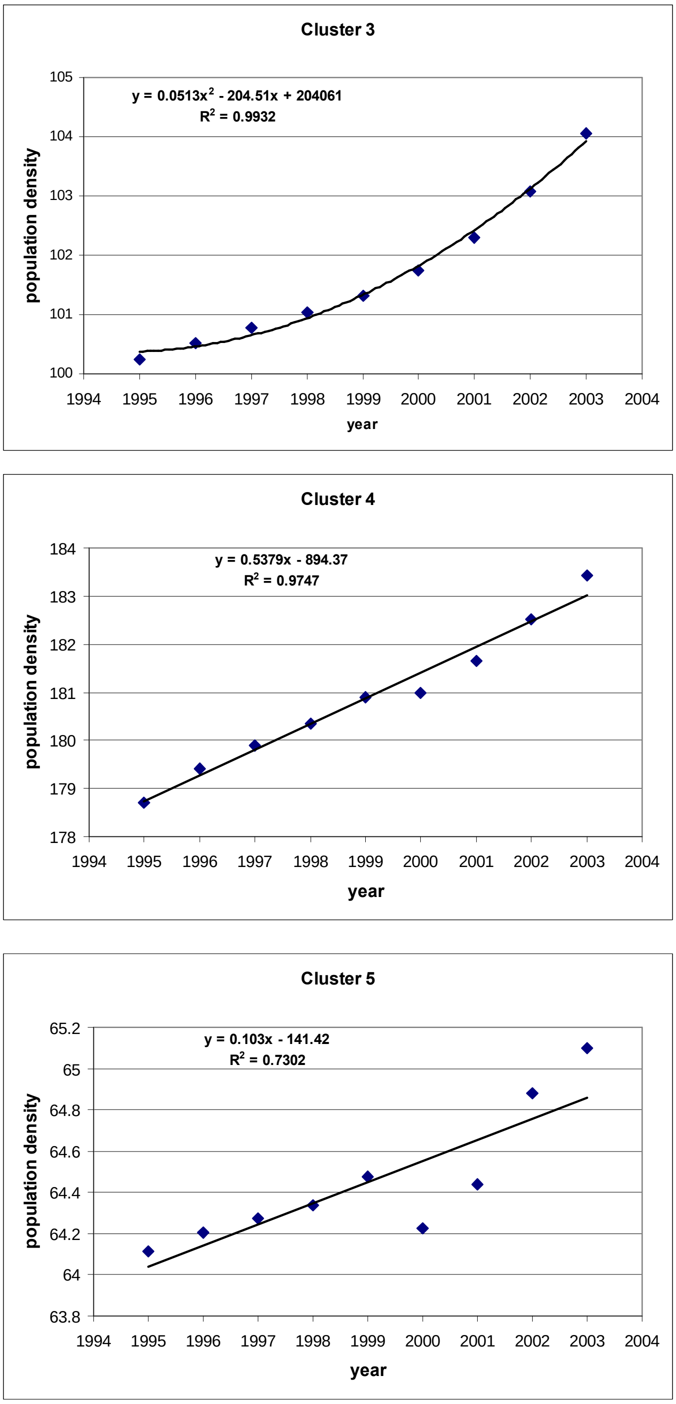

Figure 2 d, e, f. Temporal trends of population density in 5 clusters and EU-25 average NUTS-x (calculated based on Eurostat data, 2006)

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Table 4

Means of selected biophysical and socio-economic variables within 5 clusters and the EU-25 average NUTS-x

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	EU-25
Area (km^2)	6,451	9,162	10,075	6,879	11,108	8,207
Length of vegetative period (days)	236.8	227.7	346.4	265.2	197.9	257.8
Evapotranspiration (mm)	551.5	471.5	837.2	486.6	515.1	561.1
Precipitation in vegetation period (mm)	449.2	433.3	315.1	482.8	497.8	448.3
Mean temperature in vegetation period (^{o}C)	12.1	11.8	15.8	11.8	9.5	12.1
Agricultural area (% of total)	53.6	62.5	49.7	64.8	17.1	52.0
Agricultural land in mountain area (% of total AA)	45.0	no data	30.9	7.2	48.2	23.0
Number of farms in mountain area (% of total number)	37.8	no data	27.6	6.9	47.1	21.4
Annual average population (1000 inh)	452	956	1056	1248	785	959
Population density (inh./km^2)	202	107	146	228	1246	372
Economically active population (% of total population)	44.5	46.3	41.2	46.9	48.6	45.8
Crude birth rate (births/1,000inh.)	9.0	10.2	9.9	11.7	10.7	10.5
Crude death rate (deaths/1,000inh.)	11.7	9.2	9.9	9.7	10.1	10.2
Natural population growth (pers./1,000inh.)	-2.72	0.96	0.00	2.06	0.69	0.36
Total unemployment rate (% of total economically active)	10.2	20.5	13.2	6.1	7.4	9.4
Males unemployment rate (% of males economically active)	9.7	19.0	9.2	5.2	7.0	8.2
Females unemployment rate (% of females economically active)	11.1	22.3	19.4	7.2	7.9	11.2
Unemployment rate under 25 (% of economically active under 25)	20.7	44.2	28.5	13.0	15.9	20.1
Total employment (% of economically active)	85.4	75.9	88.7	87.2	95.0	87.4
Employment in agriculture, hunting, forestry and fishing (% of economically active)	8.3	23.6	10.7	3.6	3.9	7.4
Employment in industry (% of economically active)	28.5	19.7	20.6	24.2	21.7	23.7
GDP (€/inh.)	8,987	4,504	15,680	24,010	27,303	18,627
Total number of farms	15,400	no data	46,106	13,585	5,932	19,304
Farms < 5 ha (% of total number)	36.5	no data	57.3	27.6	27.7	34.6
Farms > 50 ha (% of total number)	22.0	no data	9.1	26.8	16.3	20.8

Input variables from Eurostat (2006) and IPCC climate data base.

regions in Portugal (Figure 1). Regions within cluster 2 can be defined as rural, economically and socially weak. NUTS-x regions belonging to cluster 2 face serious unemployment problems with the mean unemployment rate as high as 20.5% (Table

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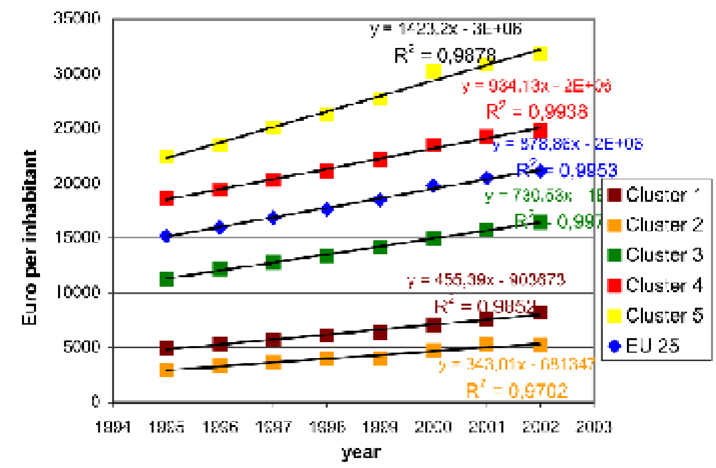

Cluster	GDP growth [%]
1	9.23
2	11.57
3	6.50
4	5.01
5	6.33
EU 25	**5.77**

Figure 3. Temporal trends of GDP and growth rate for 5 clusters and EU-25 average NUTS-x (calculated based on Eurostat data, 2006)

4). The unemployment rate has increased significantly since 1999 (Figure 4). Considering land use structure and employment, it is characterized by a large contribution of agricultural areas (62.5% of the total cluster area) and high employment in the agricultural sector at 23.6% (Table 4) – these facts indicate a strong rural character of this cluster. The population density is the lowest among all clusters, however a slight increasing trend of density (Figure 2) and natural population growth has been observed since 2000, manifested by birth/death rate over 1 (Table 4). Mean GDP value is dramatically lower than for other clusters – it does not exceed one-quarter of the overall EU-25 mean. However, the GDP growth rate is the highest (11.5%) among all clusters, which is to be expected as the initial base level was very low (Figure 3).

The transition of agricultural land into artificial surfaces within cluster 2, relative to its total area, comes to 0.11%, which is half the level within the entire EU-25 (0.20%) – Table 5. This is comparable with cluster 1. However, the distribution of this change among artificial classes is somewhat different – in cluster 1, conversion was equally distributed among industrial/commercial surfaces, urban and dump sites, whereas in cluster 2, the transition into an urban fabric predominates. This indicates weaker investment within the commercial and transport sectors. Conversion of agricultural land into forests comes to 0.10% relative to the clusters' total area, which is comparable to that of the EU-25 rate (Table 5).

Cluster 3 consists of 73 NUTS-x regions covering almost 18.65% of the EU-25. This includes mainly Southern European regions, southern France, most of Spain, southern Italy and Greece. Based on geographical location and input variables, this cluster can be defined as southern, economically and socially weak, relative to leading western EU regions or even the European average (Figure 1). This cluster represents

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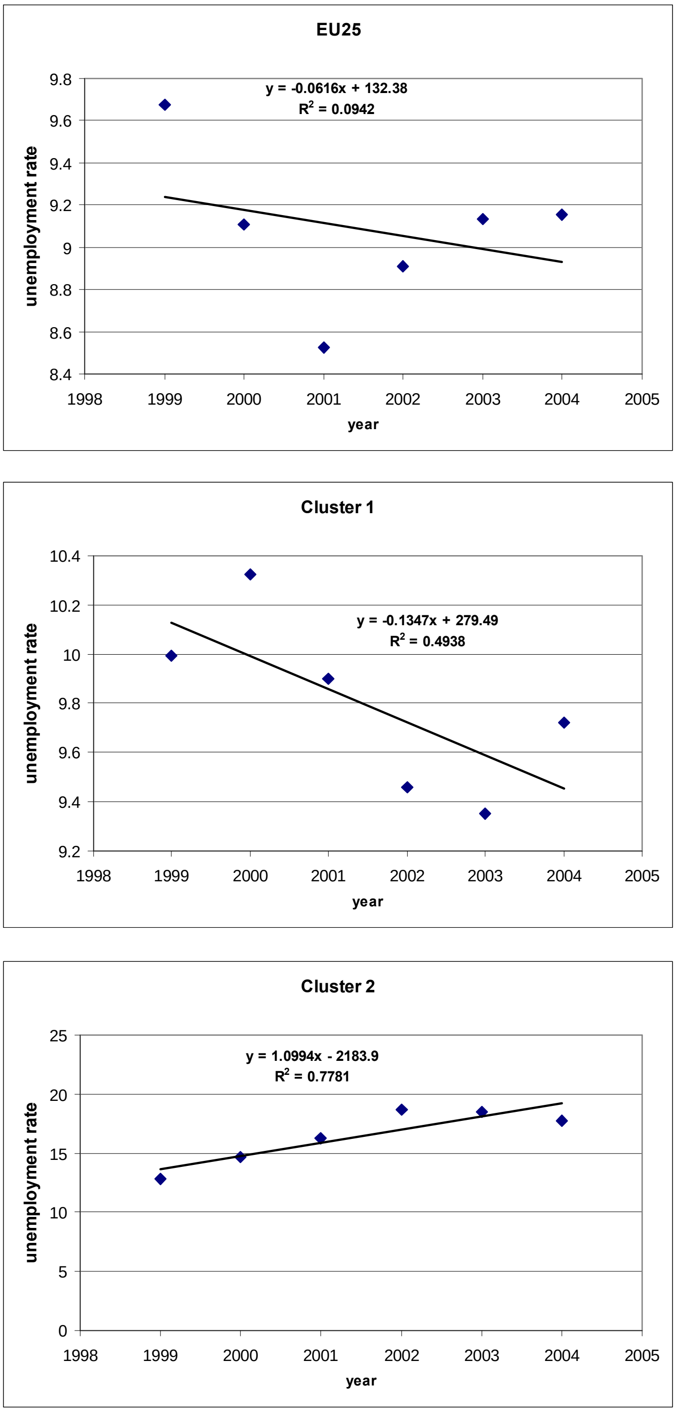

Figure 4 a, b, c. Temporal trends of unemployment rate in 5 clusters and EU-25 average NUTS-x

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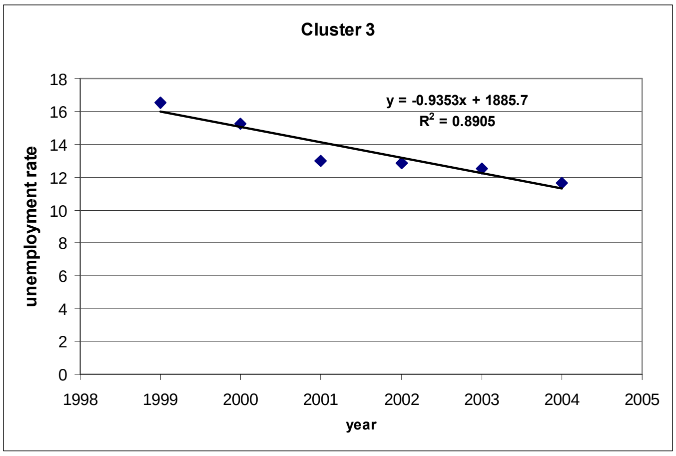

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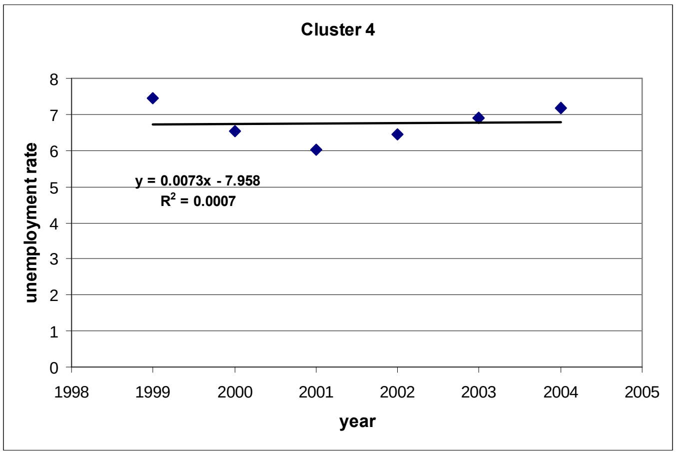

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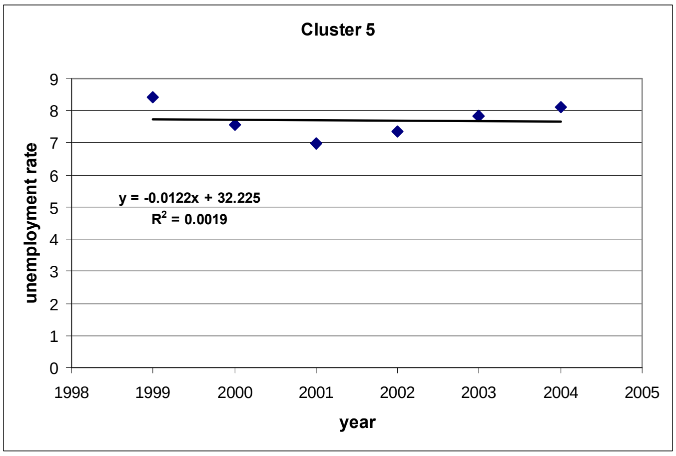

Figure 4 d, e, f. Temporal trends of unemployment rate in 5 clusters and EU-25 average NUTS-x

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Table 5

Summary of land use net flows between various land use classes in clusters (1990–2000)

Type of transition		Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	EU 25
Agricultural area - Artificial areas	ha	52900	40802	171401	511849	23316	**800268**
	% total area	0.09	0.11	0.23	0.40	0.02	**0.20**
Agricultural area - Forest and semi natural areas	ha	20347	26134	-92385	83502	-906	**36692**
	% total area	0.03	0.07	-0.12	0.06	0.00	**0.01**
Arable land - Forest and semi natural areas	ha	11702	8145	-27886	28619	-807	**19773**
	% total area	0.02	0.02	-0.04	0.02	0.00	**0.00**
Pastures - Forest and semi natural areas	ha	10603	11499	1937	21158	2298	**47495**
	% total area	0.02	0.03	0.00	0.02	0.00	**0.01**
Arable land - Permanent crops	ha	-1080	-2103	71099	-18917	109	**49108**
	% total area	0.00	-0.01	0.10	-0.01	0.00	**0.01**
Arable land - Pastures	ha	187857	-10638	-21430	-111457	2011	**46343**
	% total area	0.31	-0.03	-0.03	-0.09	0.00	**0.01**
Permanent crops - Pastures	ha	3761	121	-196	-140	-25	**3521**
	% total area	0.01	0.00	0.00	0.00	0.00	**0.00**
Permanent crops - Heterogeneous agricultural areas	ha	-1368	-3669	-28720	182	365	**-33210**
	% total area	0.00	-0.01	-0.04	0.00	0.00	**-0.01**
Pastures - Heterogeneous agricultural areas	ha	27716	2783	2989	-20736	712	**13464**
	% total area	0.05	0.01	0.00	-0.02	0.00	**0.00**
Agricultural areas - Urban fabric	ha	16823	24250	81821	238228	12251	**373373**
	% total area	0.03	0.07	0.12	0.20	0.01	**0.10**
Agricultural areas – Industrial, commercial and transport units	ha	15454	5359	43816	142823	4868	**212320**
	% total area	0.03	0.01	0.06	0.12	0.01	**0.05**
Agricultural areas – Mine, dump and construction sites	ha	19001	10765	39891	71420	2642	**143719**
	% total area	0.03	0.03	0.05	0.07	0.00	**0.05**

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a transitional nature, between industrial and rural areas, as the employment in agriculture is 10.7%. Additionally, the structure of agricultural holdings is scattered, as almost 60% of farms have a total area below 5 hectares. Natural population growth is negligible (Table 4), whereas there is almost exponential increase of population density, due to migration (Figure 2). The economically active population is the lowest (41.2%), relative to other clusters and the EU-25 mean (45.8%); (Table 7). Also, unemployment is considerably higher than in the EU-25 (13.2 and 9.4% respectively), and female unemployment is twice as high relative to that of the male rate (Table 4). GDP is slightly lower than for the EU-25. However, its relative growth is comparable to the EU (Table 4, Figure 3). It is worth pointing out that there has beena a decline in unemployment from over 16% to 11.6% within the five year period.

The unique feature of land use change in this cluster is a transition of a substantial area of forests and semi-natural areas into agricultural land, leading to a net loss of 0.12% of the forest, relative to the total cluster area (Table 5). These flows are typical for the Iberian Peninsula, where there is some pressure from intense agricultural production demanding more space (EEA, 2006a).

The transition of agricultural land into artificial surfaces is 10% higher relative to the EU-25 – 0.23% vs. 0.20% (Table 5). An increase of urban fabric is comparable to that of the EU-25 (0.11 and 0.10%, respectively). Commercial land and dump site expansion, at the expense of agricultural land, is comparable to the EU trend (Table 5). There is a remarkable change within agricultural land reflected by a conversion of arable land into permanent crops – 0.1% relative to the total cluster area (Table 5). This indicates a significant structural change in agricultural production, such as shifting to more profitable crops – vineyards and olives for example.

Cluster 4 represents the largest area at 32.35% of the EU territory and consists of 80 NUTS-x regions (Table 3). Based on geographical location and socioeconomic criteria it can be defined as western, economically strong and socially balanced cluster of regions (Figure 1, Table 2). It is characterized by a low unemployment rate (6.1%), which is considerably below the EU average (9.4%) and less than a third of the eastern, rural and economically weak group of regions in cluster 2 (20.5%). There is significantly lower unemployment in the under-25 age group, relative to the EU-25 – 13.0% and 20.1%, respectively. It is apparent that economic conditions attract a younger population, as reflected by natural growth coming to 2.06 infants per 1000 inhabitants – this is nearly six times higher than the EU-25 average (0.36%), and dramatically contrasts with the industrial cluster 1 facing a negative growth – Table 4. It should be mentioned that the values of natural population growth are given per thousand inhabitants – absolute numbers are low in all clusters, but the relative differences between clusters show different demographic trends. The growth of population density (considering migration) is linear, and twice as fast, on an absolute basis, than that of the EU-25 (Figure 2).

The GDP is more than 30% higher, as compared to the EU-25 average, and over six times more than in the eastern, rural cluster 2 (Table 4). The relative GDP growth

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is 5%, which is slightly below the EU-25 average (Table 4). The absolute growth throughout the period of 1995–2002 is linear (Figure 3).

The structure of agricultural holdings is fundamentally different than in other European regions, as 26.8% of the total number of farms is larger than 50 hectares. This cluster also has a higher contribution of agricultural land in the total area than within the entire EU (64.8% and 52%, respectively).

A distinct feature of land use change is a dramatic conversion of agricultural land into artificial surfaces with a rate twice as high as that for the EU-25 – 0.4% versus 0.2% relative to the total area – Table 5. This flow is mainly into urban fabric (0.20%) and industrial-commercial-transport class (0.12%). This indicates that land use change within this cluster is mainly driven by urbanization responding to GDP size and growth rate. Within agricultural land there is a detrimental trend leading to a loss of pastures, which are converted into arable land – 0.09% on a net bases, relative to the total cluster area (Table 5). Forests within this cluster seem to be well protected, and on the net bases their area increased at considerably higher rate than that for the EU-25 – 0.06% and 0.01%, respectively (Table 5).

Cluster 5 is defined as economically strong, of urban character and includes areas around metropolitan European cities, as well as much less urbanized regions in Sweden, Finland, Austria, France, UK and Italy that are non-industrial and non-agricultural. The contribution of agricultural land in this cluster is small and equals only 17.1% versus 52% for the average EU NUTS-x region. It has a large population density (1246 persons/km^2), which is several times higher than in the average NUTS-x region (Table 4). Natural population growth is higher than in the average NUTS-x region – 0.69 and 0.36 pers./1000 inhabitants, respectively. There is a steady positive trend in population density growth since 1995, however, there was a decline at the beginning of the millennium – but since then the increase in the population density growth is even faster than in the previous decade (Figure 2). GDP-relative growth is faster, as compared to the EU average – 6.33% and 5.77%, respectively (Table 4). The unemployment rate is low 7.4% versus 9.4% in the averageEU-25 NUTS-x region. It is remarkable that GDP is about 50% higher than the average and more than six times higher than in the eastern, rural cluster 2 (Table 4).

Regarding land use change within this cluster, there is relatively little pressure on agricultural land conversion into artificial surfaces – 0.02% of the total cluster area, as compared to 0.20% in the average EU NUTS-x region. In general, the land use structure within this cluster is very stable and observed conversions between different classes are negligible both on the total and net bases (Table 5). However, this can be underestimated, since a generalization of the change layer CLC1990/2000 detects patches of change larger than 5 ha, and therefore a scattered pattern of urban development may not be fully captured (EEA, 2006b).

3.2. RELATIONSHIPS BETWEEN LAND USE CHANGE, BIOPHYSICAL AND SOCIO-ECONOMIC VARIABLES

There is no single factor which could explain changes in land use and the transition

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between different classes. Data in Tables 6-10 demonstrates a correlation matrix for the five clusters, reflecting relationships between flows of land use functions, landscape indicators, selected climate parameters and socio-economic variables. There is a number of statistically highly significant correlation coefficients, but individually they do not explain an observed variability of the land use change within clusters. Nevertheless, these correlations can be indicative of multiple drivers controlling conversion processes – both biophysical and socio-economic features. They also show that even on an aggregated level, the impact of land use change on landscape diversity is detectable.

In cluster 1, there is a tendency for a stronger urbanization pressure with an increasing share of small farms. In contrast, in areas with an increasing contribution of large holdings, agricultural activity seems to protect the land from urbanization. There is also a visible impact of deforestation on the decline of landscape diversity indicators in this cluster – a positive correlation with the length of vegetation period and temperature indicates that this is a problem in southern regions of this cluster (Table 4). Flows of agricultural land into forests tend to correlate with an increasing share of small holdings, indicating that marginal land in areas of subsistence farming of low economic efficiency is forested. The shift from agricultural land into artificial areas is predominantly driven by population density, and ageing reflected in the death rate seems to have a negative impact on this process.

In the rural cluster (2) there is a significant correlation between conversion of agricultural land into forests, and evapotranspiration ($r = 0.50$), which may be indicative of afforestation of land with insufficient water supply for agricultural production – Table 7. Flows into artificial areas tend to correlate with climate indicators, but this is coincidental with higher GDP values in southern regions, which is the main driver of this process. Similarly, pressure on forests being converted into agricultural use is linked with a warmer climate in the southern part of the cluster, creating favourable conditions for crop production, but is also interactively driven by GDP creating demand for food products (EEA, 2006a). This shift tends to cause decline in landscape diversity.

In cluster 3, which mainly comprises Mediterranean regions, crude birth rate is a good proxy of flows of agricultural land into artificial surfaces and surprisingly there is no response to GDP – the correlation between birth rate and transition into commercial/industrial units is as high as $r = 0.87$ (Table 8). In the more rural parts of the cluster, pressure on agricultural land consumption tends to be lower, as indicated by employment in agriculture ($r = -0.40$). Deforestation seems to have a negative impact on landscape diversity, as reflected in correlations with ED and PD indexes. Positive correlations between expansion of artificial surfaces and SDI should not be misinterpreted, as they do not mean an improvement in landscape quality, but are rather indicative of its fragmentation.

In the western economically strong and socially balanced cluster (4), population

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density seems be a driver causing the flow from agriculture into artificial areas (r = 0.67). Employment in industry, characterizing the old economy has a negative impact on this flow (r = -0.55). GDP seems to have a limited role as a proxy of agricultural land consumption here, as it does not vary so much within this cluster. Regarding landscape quality, the conversion of agricultural land into forests seems to decrease

Table 6

Correlation between biophysical and socio-economic variables and land use changes
Cluster 1

Variable	Agricultural area - Artificial areas (%)	Agricultural areas - Urban fabric (%)	Agricultural areas – Industrial commercial and transport units (%)	Agricultural area - Forest and semi-natural areas (%)	Forest and semi-natural areas - Agricultural area (%)
IJI*	**0.22**	0.09	0.14	**0.24**	**-0.44**
ED	0.00	0.00	-0.08	**-0.23**	**-0.36**
SDI	0.11	0.05	0.01	0.00	**-0.41**
PD	**0.22**	0.15	0.08	-0.14	**-0.47**
Length of vegetation period (days)	0.08	0.01	**0.27**	**0.26**	**0.44**
Evapotranspiration (mm)	-0.06	-0.15	0.05	**0.23**	**0.46**
Precipitation in vegetation period IV-X (mm)	-0.04	-0.06	-0.07	**-0.27**	**-0.26**
Mean temperature in vegetation period (°C)	0.08	-0.03	**0.22**	**0.58**	**0.24**
Agricultural lands area (% total)	-0.16	**-0.25**	-0.12	**0.29**	-0.14
Population density (inhabitants/km^2)	**0.54**	**0.49**	**0.46**	-0.14	-0.09
Crude birth rate (inhabitants/1000)	-0.15	-0.15	-0.14	0.20	**-0.22**
Crude death rate (inhabitants/1000)	**-0.36**	**-0.33**	**-0.40**	0.11	**-0.22**
Natural population growth (inhabitants/1000)	0.21	0.19	**0.25**	0.00	0.09
Economically active population (% total population)	0.09	0.15	0.09	**-0.37**	-0.11
Total unemployment rate (% economically active)	-0.13	-0.06	**-0.23**	**-0.23**	-0.14
Total employment (% economically active)	0.14	0.13	0.20	0.19	0.13
Employment in agriculture (% economically active population)	**-0.27**	**-0.29**	**-0.29**	-0.05	0.05
Employment in industry (% economically active population)	0.12	0.09	0.20	**0.26**	0.07
GDP (€/inhabitant)	0.09	0.06	**0.24**	-0.16	**0.39**
Farms in mountain area (%)	0.02	0.06	0.02	0.08	0.20
Farms <5 ha (%)	**0.51**	**0.44**	**0.43**	**0.40**	0.00
Farms >50 ha (%)	**-0.41**	-0.30	-0.33	-0.25	0.03

* Abbreviations used: IJI - Interspersion and Juxtaposition Index , ED - Edge Density , SDI - Shanon Diversity Index , PD - Patch Density

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Table 7

Correlation between biophysical and socio-economic variables and land use changes

Variable	Agricultural area - Artificial areas (%)	Agricultural areas - Urban fabric (%)	Agricultural areas – Industrial commercial and transport units (%)	Agricultural area - Forest and semi-natural areas (%)	Forest and semi-natural areas - Agricultural area (%)
IJI*	-0.12	**-0.31**	-0.07	0.00	**-0.37**
ED	-0.03	-0.03	-0.09	-0.23	-0.03
SDI	0.04	-0.05	-0.02	-0.18	-0.09
PD	-0.16	-0.22	-0.11	-0.27	-0.24
Length of vegetation period (days)	**0.63**	**0.81**	**0.81**	0.28	**0.86**
Evapotranspiration (mm)	**0.53**	**0.77**	**0.66**	**0.50**	**0.81**
Precipitation in vegetation period IV-X (mm)	-0.12	-0.05	-0.15	0.24	-0.05
Mean temperature in vegetation period (°C)	**0.49**	**0.58**	**0.75**	0.14	**0.63**
Agricultural lands area (% total)	-0.14	**-0.34**	**-0.33**	**-0.68**	**-0.38**
Population density (inhabitants/km^2)	0.22	0.13	**0.32**	-0.10	0.10
Crude birth rate (inhabitants/1000)	0.09	0.18	-0.15	0.07	0.15
Crude death rate (inhabitants/1000)	0.05	0.03	0.19	0.14	0.06
Natural population growth (inhabitants/1000)	0.02	0.10	-0.19	-0.03	0.07
Economically active population (% total population)	**0.34**	0.21	0.09	0.17	0.27
Total unemployment rate (% economically active)	-0.30	**-0.53**	**-0.36**	0.16	**-0.55**
Total employment (% economically active)	-0.11	0.07	-0.30	-0.08	0.12
Employment in agriculture (% economically active population)	-0.21	-0.25	**-0.41**	**-0.49**	-0.22
Employment in industry (% economically active population)	0.21	**0.44**	0.11	0.28	**0.46**
GDP (€/inhabitant)	**0.58**	**0.73**	**0.84**	0.24	**0.77**
Farms in mountain area (%)	No data	No data	No data	No data	No data
Farms <5 ha (%)	No data	No data	No data	No data	No data
Farms >50 ha (%)	No data	No data	No data	No data	No data

* Abbreviations used: IJI - Interspersion and Juxtaposition Index , ED - Edge Density , SDI - Shanon Diversity Index , PD - Patch Density

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Table 8

Correlation between biophysical and socio-economic variables and land use changes Cluster 3

Variable	Agricultural area - Artificial areas (%)	Agricultural areas – Urban fabric (%)	Agricultural areas - Industrial commercial and transport units (%)	Agricultural area - Forest and semi-natural areas (%)	Forest and semi-natural areas - Agricultural area (%)
IJI*	0.14	0.14	0.11	-0.03	0.08
ED	0.09	0.11	0.05	-0.19	**-0.31**
SDI	**0.29**	**0.30**	**0.24**	0.02	0.05
PD	0.14	0.17	0.11	-0.21	**-0.32**
Length of vegetation period (days)	0.13	0.18	0.10	0.14	**0.27**
Evapotranspiration (mm)	0.11	0.12	0.13	-0.01	0.18
Precipitation in vegetation period IV-X (mm)	-0.13	-0.11	-0.13	**-0.24**	**-0.36**
Mean temperature in vegetation period (°C)	0.16	0.17	0.16	0.15	**0.39**
Agricultural lands area (% total)	-0.08	-0.06	-0.11	-0.01	-0.04
Crude birth rate (inhabitants/1000)	**0.79**	**0.74**	**0.87**	0.09	-0.02
Crude death rate (inhabitants/1000)	**0.28**	**0.26**	**0.25**	-0.09	0.12
Natural population growth (inhabitants/1000)	**-0.25**	-0.20	**-0.30**	0.01	-0.17
Economically active population (% total population)	**0.41**	**0.36**	**0.36**	**0.28**	0.13
Total unemployment rate (% economically active)	-0.11	-0.06	-0.10	0.10	**0.49**
Total employment (% economically active)	0.02	0.05	0.00	-0.02	-0.09
Employment in agriculture (% economically active population)	**-0.40**	**-0.38**	**-0.40**	-0.10	-0.04
Employment in industry (% economically active population)	0.10	0.08	0.15	0.03	0.01
GDP (€/inhabitant)	0.22	0.17	0.22	-0.07	-0.23
Growth population (inhabitants/1000)	**0.31**	**0.27**	**0.32**	-0.06	0.17
Farms in mountain area (%)	-0.14	-0.13	-0.13	0.03	-0.04
Farms <5ha (%)	0.19	0.22	0.21	0.03	-0.04
Farms >50ha (%)	-0.14	-0.17	-0.16	-0.02	0.03

* Abbreviations used: IJI - Interspersion and Juxtaposition Index , ED - Edge Density , SDI - Shanon Diversity Index , PD - Patch Density

landscape diversity, as reflected by a negative correlation with ED (r = -0.24) and PD (-0.19) – these coefficients are very low, although they are highly significant, as the number of NUTS units in this cluster is 186.

In the urban, non-agricultural and non-industrial cluster (5), where there is a sig-

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Table 9

Correlation between biophysical and socio-economic variables and land use changes Cluster 4

Variable	Agricultural area - Artificial areas (%)	Agricultural areas - Urban fabric (%)	Agricultural areas - Industrial commercial and transport units (%)	Agricultural area - Forest and semi-natural areas (%)	Forest and semi-natural areas - Agricultural area (%)
IJI*	**0.20**	**0.24**	0.12	0.10	-0.08
ED	**-0.15**	**-0.17**	-0.03	**-0.24**	0.08
SDI	**0.19**	**0.23**	**0.15**	-0.01	0.08
PD	-0.10	-0.14	0.01	**-0.19**	0.07
Length of vegetation period (days)	0.02	0.00	0.01	-0.03	**0.25**
Evapotranspiration (mm)	-0.13	-0.10	-0.11	-0.03	**0.38**
Precipitation in vegetation period IV-X (mm)	**-0.15**	-0.11	**-0.18**	-0.06	-0.08
Mean temperature in vegetation period (°C)	-0.04	-0.03	0.08	-0.07	**0.28**
Agricultural lands area (% total)	0.02	0.02	-0.03	0.08	-0.09
Population density (inhabitants/km^2)	**0.64**	**0.58**	**0.60**	0.01	**-0.15**
Crude birth rate (inhabitants/1000)	**0.29**	**0.27**	**0.20**	**0.21**	0.03
Crude death rate (inhabitants/1000)	**-0.36**	**-0.33**	**-0.35**	**-0.21**	-0.02
Natural population growth (inhabitants/1000)	**0.35**	**0.32**	**0.29**	**0.23**	0.04
Economically active population (% total population)	**0.34**	**0.34**	**0.23**	**0.22**	-0.09
Total unemployment rate (% economically active)	**-0.21**	**-0.26**	-0.03	-0.12	0.13
Total employment (% economically active)	**-0.62**	**-0.68**	**-0.57**	**-0.44**	0.02
Employment in agriculture (% economically active population)	**-0.40**	**-0.38**	**-0.43**	-0.06	**0.19**
Employment in industry (% economically active population)	**-0.55**	**-0.56**	**-0.49**	**-0.34**	-0.06
GDP (€/inhabitant)	**0.30**	**0.29**	**0.15**	0.01	-0.07
Farms in mountain area (%)	**-0.16**	-0.14	**-0.15**	-0.06	0.11
Farms <5ha (%)	0.02	0.05	0.10	-0.14	0.00
Farms >50ha (%)	**-0.28**	**-0.35**	**-0.27**	-0.07	0.06

* Abbreviations used: IJI - Interspersion and Juxtaposition Index , ED - Edge Density , SDI - Shanon Diversity Index , PD - Patch Density

nificant contribution of mountainous areas, the amount of agricultural land converted into other functions correlates negatively with the percentage of farms in the mountain areas (r = -0.48) – this is a surrogate of a negative relationship with altitude, indicating that urbanization tends to avoid expansion into mountainous landscapes ei-

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Table 10

Correlation between biophysical and socio-economic variables and land use changes
Cluster 5

Variable	Agricultural area - Artificial areas (%)	Agricultural areas - Urban fabric (%)	Agricultural areas – Industrial commercial and transport units (%)	Agricultural area - Forest and semi-natural areas (%)	Forest and semi-natural areas - Agricultural area (%)
IJI*	**0.38**	**0.38**	0.25	0.18	-0.23
ED	**0.45**	0.32	**0.33**	0.14	0.16
SDI	**0.42**	0.30	0.26	0.18	-0.01
PD	**0.65**	**0.41**	**0.50**	0.22	-0.04
Length of vegetation period (days)	0.27	0.20	0.23	-0.03	0.00
Evapotranspiration (mm)	-0.23	-0.10	-0.24	0.05	0.28
Precipitation in vegetation period IV-X (mm)	**-0.48**	**-0.34**	**-0.37**	-0.10	0.02
Mean temperature in vegetation period (°C)	**0.47**	**0.36**	**0.39**	0.14	0.04
Agricultural lands area (% total)	0.27	0.14	0.21	0.10	0.08
Population density (inhabitants/km^2)	0.20	0.14	0.19	-0.01	-0.21
Crude birth rate (inhabitants/1000)	-0.07	-0.05	0.03	-0.32	-0.17
Crude death rate (inhabitants/1000)	0.21	0.01	0.17	**0.45**	0.09
Natural population growth (inhabitants/1000)	-0.15	-0.04	-0.07	**-0.46**	-0.16
Economically active population (% total population)	-0.04	-0.04	-0.07	-0.07	-0.19
Total unemployment rate (% economically active)	0.06	0.17	0.15	-0.27	0.17
Total employment (% economically active)	0.00	-0.32	0.16	0.01	-0.11
Employment in agriculture (% economically active population)	**-0.47**	**-0.36**	**-0.35**	-0.06	**0.60**
Employment in industry (% economically active population)	0.04	-0.21	0.16	0.11	-0.14
GDP (€/inhabitant)	0.01	-0.22	0.04	-0.19	-0.23
Farms in mountain area (%)	**-0.48**	-0.33	**-0.49**	-0.07	0.27
Farms <5ha (%)	**0.48**	**0.59**	0.30	-0.18	-0.16
Farms >50ha (%)	-0.32	-0.36	-0.21	0.38	**0.48**

* Abbreviations used: IJI - Interspersion and Juxtaposition Index , ED - Edge Density , SDI - Shanon Diversity Index , PD - Patch Density

ther through limits in suitability for construction, or, to some extent, also responding to rules of spatial planning. A similar coinciding relationship is observed with precipitation (r = -0.48), which may also mean that there is less intense expansion in the northern

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altitudes of this cluster. The expansion of artificial surfaces on agricultural land in this cluster seems to be occurring at the expense of small farms below 5 ha (r = 0.48). Flows of agricultural land into urbanization in this cluster do not correlate with population density and other demographic indicators, as well as with GDP and employment indicators. Partially, this may be due to the fact that these changes are not detected adequately, and on the other hand the variability of these parameters may be too small to show any relationships. It is surprising that the transition of agricultural areas into artificial surfaces in the urbanized areas increases with the increasing values of landscape matrices – e.g. the correlation coefficient between the rate of this transition and patch density index (PD) is 0.65 – Table 10. This indicates that urbanization in these regions is leading to a fragmentation of landscapes, affecting their functions (Mander et al., 2005).

Based on the analysis, it can be concluded that the behaviour of land use change is different in different clusters – in general, loss of agricultural land is driven by GDP, demography and employment structure, and the character of agricultural systems. However, biophysical and geographical components seem to interact strongly with socio-economic processes. Increasing values of landscape indicators responding to agricultural land consumption seem to be a consequence of landscape fragmentation. The discussed relationships may provide a useful input to the identification of causal chains explaining land use change, however, many of these correlations are difficult to interpret in terms of cause-impact relation. It is critical that even parameters which have a high correlation with the observed flows are carefully assessed, as they may not be corresponding with real driving forces.

3.3. EXPLAINING LAND USE CHANGES – MULTIPLE REGRESSION MODELS

Equations showed in the Table 11 present a set of multiple regression models, developed by using a step-wise selection of variables and explain the conversion of agricultural land into artificial surfaces as a whole (CORINE level 1), and also separately, into classes, such as urban fabric and industrial/commercial/transport units (CORINE level 2). An interpretation of these equations provides evidence for the complex character of the change, which can, however, be satisfactorily described by number of basic economic and socio-economic parameters, such as GDP, employment, population density, economically active population, as well as birth and death rates. These parameters taken together can quite well depict a pressure of urbanization on agricultural land both for the entire EU and within a particular cluster of regions characterized earlier.

For the entire EU-25, as much as 67% of the observed variability of the land use change can be explained (Table 11). In order to better assess the causal importance of different variables, values of determination coefficients (R^2) are shown in the tables, indicating how adding a particular variable in a step-wise selection process improves the strength of the regression model and fit between measured and regressed data. It

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is worth noting that adding variables to regression in a step wise selection process sometimes does not significantly improve the R^2 (Table 11) – however, presenting these variables shows that different parameters can be considered as surrogates of land use change drivers.

For example, in the western economically strong and socially balanced cluster 4 (Figure 1), the model consisting of six parameters gives the R^2 of 0.9, but using three variables only, such as total employment, population density and GDP, can explain as much as 87% of agricultural land flows into artificial surfaces within 1990–2000 period (Table 11). It is evident within different clusters, that drivers of a land use change, additional to these main factors, may vary, and the ability of the regressions to explain changes is also different (Table 11). It is remarkable that the prediction power of these equations, as given by R^2, in certain cases improves significantly when analyzing conversion of an agricultural land into level 2 classes, such as urban fabric and industrial/commercial/transport units (Tables 12-13). Interestingly, this is very evident for cluster 1, comprised of industrial, socially and economically weak regions – the R^2 for the equation explaining transition of agricultural land into artificial surfaces was 0.48, whereas regressions for the urban fabric and industrial functions give much better fits, $R^2 = 0.69$ (Table 12-13). In the southern economically and socially weak cluster 3, a similarly high R^2 (0.66) can be achieved by using population density and birth rate to construct the regression equation. In the economically strong western cluster 4, conversion into urban fabric can be explained by total employment and GDP only ($R^2 = 0.80$) – other socio-economic parameters including population density and unemployment rate seem to be less important descriptors of a change (Table 12). It is also remarkable that in cluster 5, comprised mainly of major urban areas, the regression model adequately explains variability of flow into artificial surfaces ($R^2 = 0.62$) but not for separate classes such as urban fabric and industrial functions (Table 11-13). This may be a consequence of uncertainty of land use change analysis in urban zones, where many discrete flows could not be detected at a resolution used in CORINE methodology (EEA, 2006b) and therefore combined level 1 class of artificial surfaces is more adequate for an analysis.

The quality of regression equations that account for a conversion of agricultural land into industrial/commercial/transport units is also satisfactory, since over 60% of the observed variability can be explained in clusters 1-4 (Table 13). The demand for industrial land in the industrial, economically weak cluster (1), can be basically explained by population density and GDP ($R^2 = 0.65$). The same transition in the rural cluster 2 can be explained just by the size of GDP ($R^2 = 0.73$).

Other types of agricultural land conversion, such as the conversion into forests, cannot be properly explained by socio-economic variables (Table 14). The determination of relationships with socio-economic variables is very weak, which suggests an important role of other drivers, like poor land quality, large contribution of less favoured areas (LFA) and limited profitability of agricultural production.

The presented analysis clearly indicates that agricultural land use change to an

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Table 11

Stepwise regression models for land use changes in EU – agricultural into artificial areas

Dependent variable (conversion)	Model R^2	Independent variable	Coefficient (slope)	R^2
EU25				
Agricultural Areas – Artificial areas	0.67	Constant	1.463133	
		Employment: Total	-0.012446	0.27
		GDP	0.000009	0.60
		Population density	0.000094	0.63
		Unemployment rates	-0.011598	0.66
		Crude birth rate	0.008814	0.67
		Economically active population	-0.004418	0.67
		Crude death rate	-0.010017	0.67
		Cluster 1		
Agricultural Areas – Artificial areas	0.48	Constant	0.956035	
		Population density	0.000369	0.42
		Crude death rate	-0.045238	0.47
		Economically active population	-0.007829	0.48
		Cluster 2		
Agricultural Areas – Artificial areas	0.78	Constant	-0.710596	
		GDP	0.000088	0.63
		Unemployment rates	-0.004347	0.69
		Crude birth rate	0.038111	0.71
		Crude death rate	0.039595	0.75
		Economically active population	-0.006024	0.78
		Cluster 3		
Agricultural Areas – Artificial areas	0.77	Constant	-1.27795	
		Population density	0.00153	0.71
		Crude death rate	0.04732	0.72
		Crude birth rate	0.03329	0.73
		Employment: Industry	0.00734	0.75
		Economically active population	0.00769	0.77
		Unemployment rates	0.00403	0.77
		Cluster 4		
Agricultural Areas – Artificial areas	0.90	Constant	2.775831	
		Employment	-0.018182	0.71
		Population density	0.000934	0.82
		GDP	0.000036	0.87
		Economically active population	-0.031297	0.89
		Crude death rate	-0.029372	0.89
		Unemployment rates	-0.018633	0.90
		Cluster 5		
Agricultural Areas – Artificial areas	0.62	Constant	1.836688	
		Employment: Agriculture	-0.058473	0.19
		Crude birth rate	-0.103027	0.50
		Population density	0.000050	0.58
		Economically active population	-0.006774	0.62

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Table 12

Stepwise regression models for land use changes in EU – agricultural areas into urban fabric

Dependent variable (conversion)	Model R^2	Independent variable	Coefficient (slope)	R^2
		EU25		
Agricultural Areas – Urban fabric	0.60	Constant	0.930437	
		Employment	-0.006456	0.29
		GDP	0.000005	0.53
		Population density	0.000043	0.56
		Unemployment rates	-0.005480	0.58
		Economically active population	-0.003691	0.59
		Crude death rate	-0.009641	0.59
		Crude birth rate	-0.004032	0.60
		Cluster 1		
Agricultural Areas – Urban fabric	0.69	Constant	0.140706	
		Population density	0.000087	0.57
		Crude death rate	-0.006773	0.64
		Employment: Agriculture	-0.002019	0.67
		Employment: Industry	-0.000856	0.68
		GDP	0.000001	0.69
		Cluster 2		
Agricultural Areas – Urban fabric	0.36	Constant	0.069494	
		Employment Total	-0.000818	0.15
		Economically active population	-0.001164	0.23
		GDP	-0.000001	0.30
		Crude death rate	0.003987	0.33
		Crude birth rate	0.002907	0.36
		Cluster 3		
Agricultural Areas – Urban fabric	0.72	Constant	-0.771883	
		Population density	0.000762	0.64
		Economically active population	0.005997	0.66
		GDP	-0.000001	0.68
		Crude birth rate	0.023941	0.69
		Crude death rate	0.022722	0.70
		Employment: Industry	0.004489	0.72
		Cluster 4		
Agricultural Areas – Urban fabric	0.88	Constant	1.518689	
		Employment Total	-0.010463	0.68
		GDP	0.000025	0.80
		Economically active population	-0.021832	0.84
		Population density	0.000312	0.87
		Unemployment rates	-0.013568	0.88
		Cluster 5		
Agricultural Areas – Urban fabric	0.31	Constant	0.530108	
		Births and deaths	-0.035464	0.07
		Employment: Agriculture	-0.025859	0.26
		Unemployment rates	0.009935	0.31

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Table 13

Stepwise regression models for land use changes in EU – agricultural into industrial, commercial and transport units

Dependent variable (conversion)	**Model R^2**	**Independent variable**	**Coefficient (slope)**	**R^2**
		EU25		
Agricultural Areas – Industrial commercial and transport units	0.53	Constant	0.667843	
		Employment Total	-0.003593	0.24
		GDP	0.000002	0.42
		Population density	0.000040	0.47
		Unemployment rates	-0.004775	0.49
		Economically active population	-0.004158	0.52
		Crude death rate	-0.009097	0.53
		Cluster 1		
Agricultural Areas – Industrial commercial and transport units	0.69	Constant	0.007430	
		Population density	0.000118	0.54
		GDP	0.000003	0.65
		Employment: Industry	0.000793	0.68
		Crude death rate	-0.003220	0.69
		Cluster 2		
Agricultural Areas – Industrial commercial and transport units	0.83	Constant	-0.090929	
		GDP	0.000008	0.73
		Crude death rate	0.003267	0.76
		Crude birth rate	0.003135	0.83
		Cluster 3		
Agricultural Areas – Industrial commercial and transport units	0.79	Constant	-0.356750	
		Population density	0.000587	0.72
		Employment: Industry	0.003663	0.73
		Crude birth rate	0.015199	0.74
		GDP	-0.000005	0.76
		Crude death rate	0.013654	0.78
		Economically active population	0.001805	0.79
		Cluster 4		
Agricultural Areas – Industrial commercial and transport units	0.76	Constant	1.094624	
		Employment Total	-0.004313	0.47
		Population density	0.000376	0.67
		Economically active population	-0.009862	0.70
		GDP	0.000008	0.73
		Crude death rate	-0.024693	0.74
		Crude birth rate	-0.017960	0.75
		Unemployment rates	0.007380	0.76
		Cluster 5		
Agricultural Areas – Industrial commercial and transport units	0.48	Constant	0.485286	
		Employment Agriculture	-0.018047	0.15
		Crude birth rate	-0.035399	0.40
		Population density	0.000018	0.48

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Table 14

Stepwise regression models for land use changes in EU – agricultural into forest and semi natural areas

Dependent variable (conversion)	Model R^2	Independent variable	Coefficient (slope)	R^2
		EU25		
Agricultural Areas – Forest and semi-natural areas	0.09	Constant Employment Total Crude birth rate GDP Economically active population	0.256663 -0.001087 -0.006655 0.000001 -0.001178	 0.06 0.08 0.08 0.09
		Cluster 1		
Agricultural Areas – Forest and semi-natural areas	0.32	Constant Economically active population Employment: Industry GDP Employment: Agriculture Population density Crude birth rate	0.714181 -0.011007 0.003197 -0.000005 -0.004463 -0.000048 -0.016003	 0.11 0.24 0.27 0.28 0.30 0.32
		Cluster 2		
Agricultural Areas – Forest and semi-natural areas	0.24	Constant GDP Population density Unemployment rates Crude birth rate	-0.190501 0.000026 -0.000389 0.003225 0.010336	 0.10 0.17 0.21 0.24
		Cluster 3		
Agricultural Areas – Forest and semi-natural areas	0.28	Constant Unemployment rates Employment: Industry Economically active population Population density Crude birth rate	-0.281962 0.008987 0.006182 0.005013 -0.000145 -0.008420	 0.10 0.18 0.22 0.26 0.27
		Cluster 4		
Agricultural Areas – Forest and semi-natural areas	0.34	Constant Employment Total GDP Population density Crude death rate Crude birth rate Unemployment rates Economically active population	-0.096056 -0.001987 0.000006 -0.000076 0.019052 0.015250 -0.007337 -0.002432	 0.19 0.25 0.29 0.30 0.33 0.34 0.34
		Cluster 5		
Agricultural Areas – Forest and semi-natural areas	0.36	Constant Crude birth rate Employment: Agriculture Unemployment rates	0.025110 -0.001042 0.001782 -0.001389	 0.23 0.29 0.36

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urban and an industrial function can be very well assessed by predicting trends in a few economic and socio-economic variables, such as GDP, population density, birth rate and employment. These variables can explain well over 60% of the transition processes of agricultural land into artificial surfaces as a whole, or separately, into urban and industrial functions. The remaining variability can be attributed to other factors, either to autonomous local or regional drivers related to physical and socio-economic features of space, or to policy variables. From a practical perspective, predictions of GDP, population growth and density and employment figures, generated by macroeconomic models can be distributed into NUTS-x regions, which could allow a construction of multiple regression models for the assessment of agricultural land conversion into other functions such as urbanization, commerce, industry and transport in the years to come. Moreover, in a short term-horizon of 10 years, trends of population density, GDP, and birth rates are so strongly determined that it allows the prediction of the agricultural land to be converted into artificial surfaces by just using stochastic equations within clusters of similar regions - assuming that the system is in equilibrium.

3.4. MODELLING LAND USE CHANGE

As mentioned in the introductory part, complex models are robust, but they often lack transparency, and a non-advanced user is not able to analyze the trends in process development and test for an importance of variables driving the system. System dynamic modelling and supporting tools provide an opportunity for a relatively easy way of constructing even very complex systems, based on knowledge of principle processes. In the first system dynamics work, feedback structure was portrayed by equations or stock-and-flow diagrams (SFD). In an attempt to make system dynamics accessible to a wider range of people, causal-loop diagrams (CLD) have become increasingly popular (Richardson, 1986). Richardson (1986) emphasizes that working with system dynamics without the development of formal models, such as SFDs, involves some risks, particularly in defining and understanding the polarities of causal loops in terms of behaviour over time.

Descriptive statistics can provide essential information on important variables, which are defining the behaviour and evolution of system dynamics, helping to identify main feedback mechanisms.

Originally, system dynamic modelling was used to optimize organizational processes in manufacturing, but gradually it became a powerful tool in studying natural systems, such as land use change, climate change impacts on ecosystems, or nutrient cycles in terrestrial ecosystems. In recent years, a large number of applications for system dynamic modelling have been developed in Sweden for landscape research (Haraldsson 2003, 2005). It is not intended here to develop a tool competing with sophisticated modelling frameworks, such as EITAP, IMAGE, NEMESIS, EURALIS, CAPRI, but to verify whether a simplified approach gives acceptable results, improv-

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ing the understanding of evolution of land use change throughout Europe in the context of economic growth and demographic development, when considering the variability of European regions. Difficulties arise in discussion of modelling outputs because of their frequent non-transparency and poorly documented validation, which in many cases is not presented in scientific journals. Limited comparability is also related to different time frames, different spatial resolutions, different classification and definition of outputs often in a form of different proxy variables. Apart from being prediction and simulation tools, models can serve as powerful learning tools, helping discussion forums to formalize thoughts and concepts and evaluate how they capture the behaviour of the system in question, its evolution and its sensitivity.

The model presented in this study is not spatially explicit and considers exogenous socio-economic drivers of a land use change. Dynamics are introduced by feedback between socio-economic variables and feedback between land use changes. Feedbacks caused by biophysical variables are not included, as the model operates on an aggregated, and not landscape level. Policy variables are also not included, as these are difficult to parameterize. But, regardless of this criticism, strong relationships between socio-economic factors and land use change, sometimes explaining over 80% of conversion variability, fully justify the simplification of the model to a limited number of variables.

It is difficult to fully conceptualize the evolution of the system and predict feedback mechanisms between future policy changes or changes of environmental and socio-economic conditions and land use change. Attempting a simplification of the model and reducing input variables is in agreement with an approach postulated by Haraldsson (2005), emphasizing that it is a common mistake to assume that models need to be complex and use a lot of data in order to produce credible results. A simple model has the advantage of easy access to data, although losing complexity may lead to a loss of important feedbacks. There must be a compromise between the effort to consider detailed feedback and the complexity of the problems and questions addressed by the model. In this light, the number of drivers and feedback mechanisms were reduced to a manageable amount, taking into account the availability and cost of data access, labour etc. The main assumption used here, with the resources given for the study, was to limit input variables to data accessible through EUROSTAT and CORINE. Outputs of SCENAR 2020, which is a European Commission-launched land use change modelling exercise, is used as a reference framework for socio-economic and land use developments predicted here (Nowicki et al., 2007).

The calculation of future changes of land use is based on functions and parameters included in regression models presented earlier. The descriptive statistical analysis, conducted in the first part of this study, was aimed at determining relationships between variables describing land use as a system. This step can be viewed as a system analysis prior to conceptualizing the model and drawing stock and flow diagrams (SFD), as well as casual loop diagrams (CLDs). These diagrams help to visualize thinking on how the land use system works and indicate the driving variables fundamental for retrieving the complexity of the system.

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SFDs represent a state of important variables of the system (visualized as stocks) and their interrelationships – the size of stock at given time (e.g. size of arable land or GDP as a driver) is calculated with a use of differential equations. A year interval is a basic time unit in the analysis of a land use change and the change of other variables of the system. In the numerical solution developed, the rate of change in time is calculated using regression models, where the size of change is a dependent variable – most often multivariate equations are used. This approach of using regressions to calculate time changes allows a more objective analysis, replacing expert knowledge and drawing functions controlling evolution of a given stock (variable). Commonly, experts draw such functions shaped in a way which depicts the rate of change (flows) – in this context the regression solution used here is more robust as the coefficients are calculated based on real data.

CLDs are used to visualize relations between variables controlling the system via feedback, which can be either reinforcing (positive) or balancing (negative). CLDs help to transparently show the so-called casual chains, which in a descriptive sense, are graphical representations of all the important elements and linkages showing cause-effect relationships.

The diagram shown in Figure 5 is a graphical representation of multivariate regression models developed to explain the transition of main land use functions to other uses. An area in km^2 dedicated to agriculture, urban fabric, industry and commerce is represented by solid line rectangular blocks, so-called stocks. Pipes and valves connecting stocks represent the conversion process (flow) from one land use function to another. Flows representing conversion into a given direction are regulated by coefficients from a relevant regression model – these coefficients are shown as solid line circles, the so-called converters in the dynamic system modelling terminology, marked with a proper letter index: a for agricultural land, f for forests, u for urban fabric, and i for industrial land. Conversions between basic land use classes are only shown on the diagram. Elements shown as dotted line circles and rectangular dotted line blocks, the so called "ghosts", are variables driving the conversion, as reflected by regression models developed for different transition ways, and they belong to the dynamic part of the model shown on Figure 5. The flow from one stock to another is calculated for one-year intervals, which is the basic time unit used in this kind of modelling. The dynamic part of the model (Figure 6) deals with the prediction of GDP, size of economically active population, employment in industry, services and agriculture – modelling these parameters for each year allows the calculation of changes relative to a previous year, which are then used for the regression part of the model. The difference between regression models discussed in the previous chapter and equations used here is that absolute values of parameters were replaced by their annual change (chng – difference as compared to previous year), or change ratio, relative to a previous year (chngr) Figure 6.

The dynamic of the model is reflected by feedback mechanisms affecting behaviour of variables driving land use change. Relations between variables are shown by red lines and arrows, the so-called connectors. Flows into and out of different stocks are

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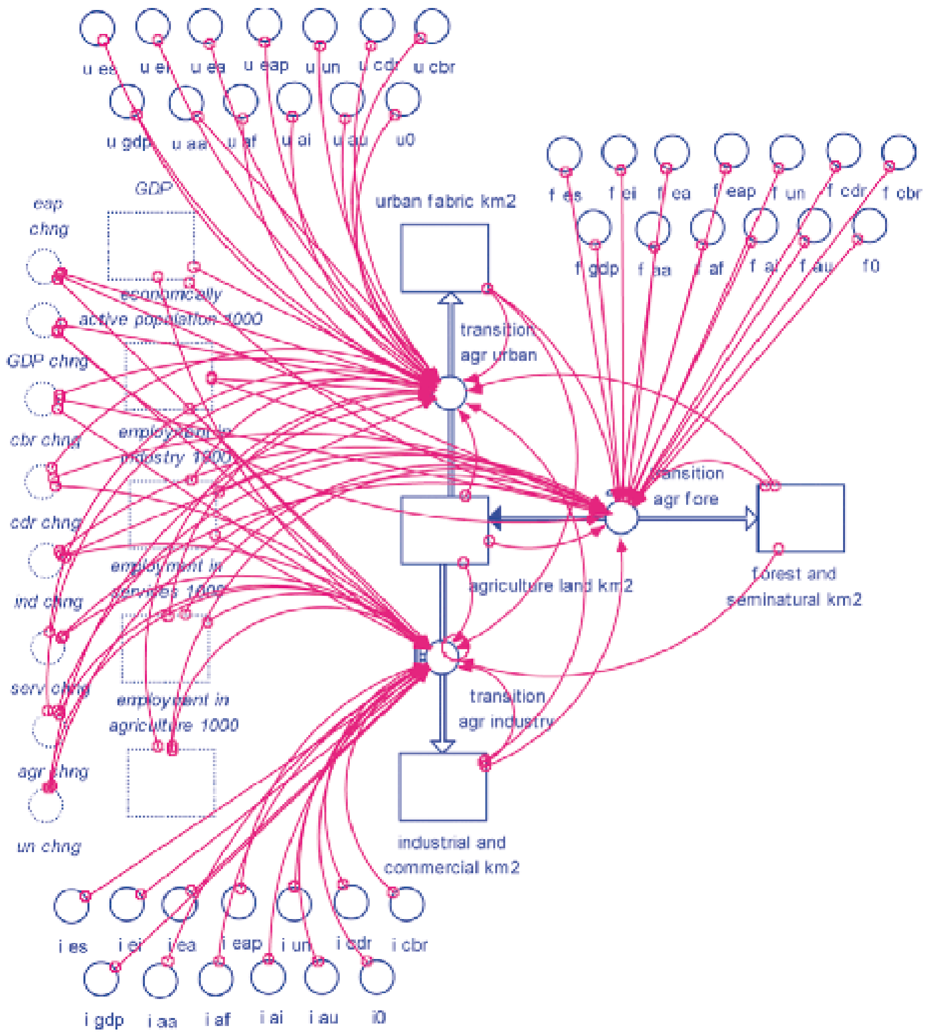

Figure 5. Stock and flow diagram (SFD) of land use change model, based on multivariate regressions accounting for a conversion of agricultural land into urban fabric (u), industry (i) and forestry (f). Abbreviations used: employment in - services (es), industry (ei), agriculture (ea), unemployment (un), crude death rate (cdr), crude birth rate (cbr), gross domestic product (gdp); areas of different land use classes: agricultural (aa), forestry (af), industry (ai), urban fabric (au), constant (0), change of absolute variable value (chng), change ratio relative to a previous year (chngr)

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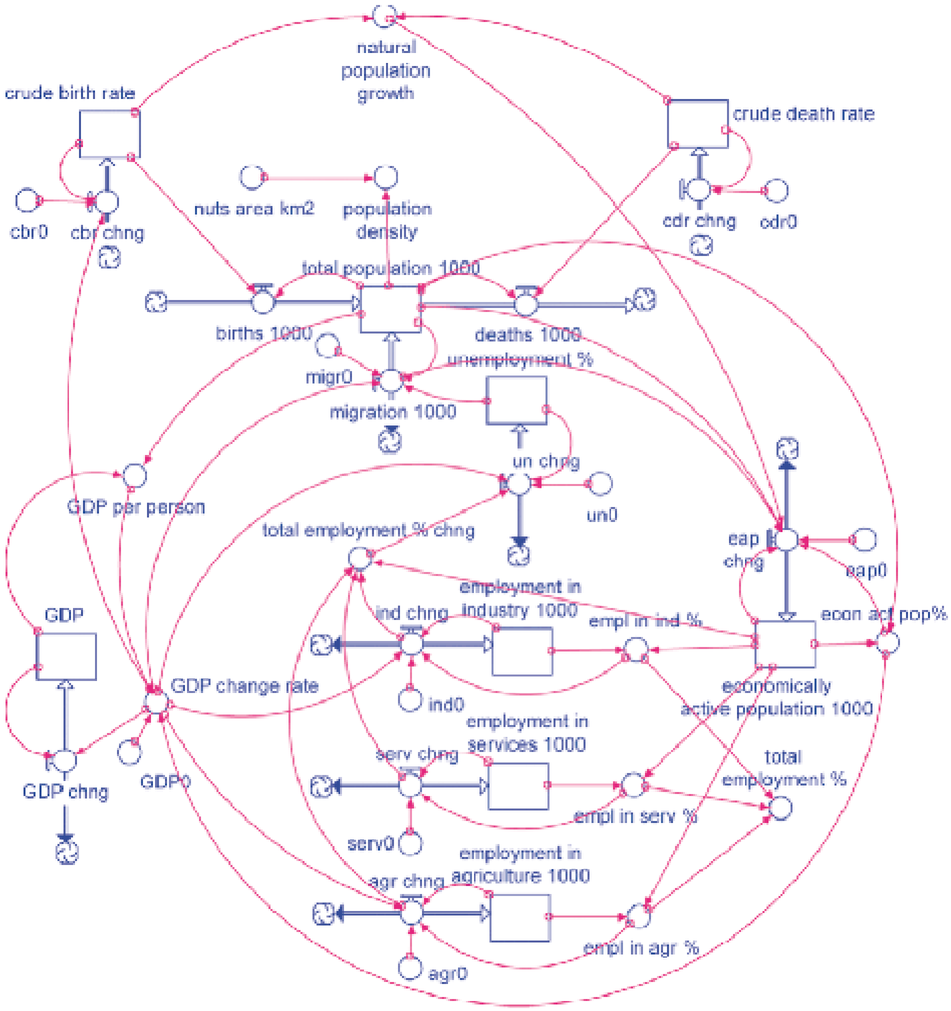

Figure 6. Stock and flow diagram (SFD) for the dynamic socio-economic part of the model. Abbreviations used: change (flow) of a variable absolute value in time (chng), unemployment (un), crude death rate (cdr), crude birth rate (cbr), gross domestic product (gdp), equation constant (cdr0) e.g. crude death rate

reflected as a change on the diagram (chng). It is important to mention that employment in different sectors – agriculture, industry, and services – is modelled as non-connected stocks, as summing them up does not give 100%. This is because the EUROSTAT definition of employment is given as the percentage ratio of persons employed in a given sector, relative to economically active population - summing the percentage of employment and unemployment reported by EUROSTAT does not yield 100%.

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Some of the relations between variables used in the model are directly derived from their definition:

a. births_1000 = total_population_1000*crude_birth_rate/1000
b. deaths_1000 = total_population_1000*crude_death_rate/1000
c. econ_act_pop% = 100*economically_active_population_1000/ total_population_1000
d. empl_in_agr_%=100*employment_in_agriculture_1000/ economically_active_population_1000
e. empl_in_ind_% = 100*employment_in_industry_1000/ economically_active_population_1000
f. empl_in_serv_% = 100*employment_in_services_1000/ conomically_active_population_1,000
g. GDP_per_person = GDP*1000000000/(1000*total_population_1000)
h. natural_population_growth_% = crude_birth_rate_%-crude_death_rate_%
i. population_density = total_population_1000*1000/nuts_area_km2
j. total_employment_% = empl_in_agr_%+empl_in_ind_%+empl_in_serv_%
k. total_employment_%_chng = (agr_chng+ind_chng+serv_chng)/ economically_active_population_1000
l. GDP_chng = GDP*GDP_change_rate

Most of the model dynamics are associated with the impact of economic variables on the population growth and migration. An example of feedback mechanisms involved in controlling the relationship between GDP, migration, economically active population and unemployment is shown on a casual loop diagram (CLD) – Figure 7. It shows four loops where feedbacks occur – reinforcing loop (R) controls a relationship demonstrating that when GDP in absolute terms increases over a time period, then GDP change rate in this period behaves in a similar manner – e.g. it either increases or declines at slower pace than it would have happened without feedback. The reinforcing loop is the main control reflecting behaviour of the economy, however, it is affected by a balancing loop controlling GDP change rate (Figure 7). In fact, transition economies represent rather low GDP increases in absolute terms, however, they lead to an increase of GDP per capita, which over time slows down an initially high GDP change rate – this is resulting in a lower GDP change in absolute terms – a fast growing economy becomes more balanced.

A similar balancing feedback mechanism controls GDP change rate, which is represented by a second loop – high values of this rate are resulting in an increased migration, in consequence reducing the population in the productive age – over a certain time it will slow down the GDP change rate. Such a pattern of GDP and migration is currently observed in new member state economies. Another balancing loop and feedback control immigration – when the economically active population decreases due to fast growth and migration (such as in the new EU member states), unemployment decreases as well – over time it increases immigration to these regions, as the economy becomes more balanced. An opposite mechanism exists in western advanced economies. These regions are represented by large GDP and slower growth rates resulting in in-migration, which increases the economically active population - over time, it will contribute either to an increase in unemployment, or its slower decline

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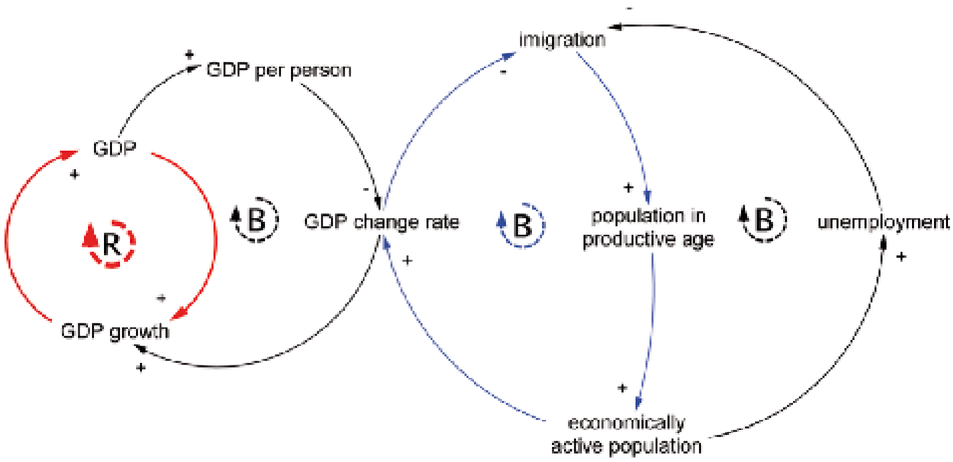

Figure 7. Casual loop diagram CLD demonstrating feedback mechanism driving land claims in the model. Terms used: GDP – absolute value gross domestic product; GDP change rate – change of absolute GDP value relative to a previous year; GDP growth – change of absolute value of GDP in a time period

as would have happened without migration. It is important to mention, in order to better understand CLD diagrams, that the odd number of minus signs in a given loop indicates that if the beginning variable increases, the end variable will always decline. A plus symbol on the arrow of a connector line indicates that the following variable will react in the same direction as the previous one – a minus symbol indicates an opposite direction. In the former EU-15, the initial size of GDP is much higher, and therefore its relative growth is considerably smaller, although immigration to these countries is a significant driver of the productive population growth. As shown on the CLD, immigration increases the population in the productive age, and thus contributes to the growth of the economically active population – this results in increasing GDP change rate of regions attracting immigrants by job opportunity related to the size of economy. The above description and conceptualization of a GDP behaviour and its relation to employment, as well as the connection between employment and migration, is in good agreement with the outputs of socio-economic and demographic process analysis conducted within the framework of the SCENAR 2020 project, which produced predictions for these key variables and for land use change for different policy and EU development scenarios until 2020 (Nowicki et al., 2007). A strong dependence between GDP and employment is also evident from other reports (European Commission, 2001).

The rational behind simplifying the socio-economic model, needed to predict the behaviour of key land use system variables, comes from the common assumptions and known relations, such as those between GDP and employment, employment and

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migration. The assumptions for population size and structure follow common demographic processes and are fully accounted for in structure of SFDs by considering birth rates, death rates and stocks of different age groups (Hilderink, 2004).

The calibration of the socio-economic part of the dynamic model was performed based on EUROSTAT data for 1995–2000, by finding coefficients for regression equations using the least sum of squares method. It is important to mention that a number of data inconsistencies are present in this dataset, including a dramatic, unlikely change of a variable trend observed in two following years (Figure 8).

The equations listed below are regression equations used to account for the relationships between rates of change (chng) of a given variable, developed for NUTS-x units. Finding the best regression equations for the key relationships was considered as a calibration of the model. Trends are not considered in the following equations in order to avoid artificial forcing of the model to a predetermined behaviour:

a) Change of birth rate per 1000 inhabitants (cbr chng)
cbr_chng = 0.299039-0.36658*GDP_change_rate-0.03198*crude_birth_rate
b) Change of death rate per 1000 inhabitants (cdr chng)
cdr_chng = 0.6879-0.07105*crude_death_rate
c) Migration in thousands (positive value in migration, negative value out migration)
migration_1000 = total_population_1000*(0.003201-0.00014*unempl.%-0.00969*GDP_change_rate)
d) Change of economically active population in thousands (eap chng)
eap_chng = economically_active_population_1000*(0.09258+0.827547*migration_1000+0.001628*
natural_population_growth-0.0019*econ_act_pop%)
e) Change of unemployment % (un chng)
un_chng = 0.385284-30.0843*total_employment_%_chng+3.499657*GDP_change_rate-
0.0819*unemployment_%
f) Change of employment in agriculture in 1000 persons (agr chng)
agr_chng = employment_in_agriculture_1000*(-0.02088+0.073695*GDP_change_rate-
0.00036*empl_in_agr_%)
g) Change of employment in industry in 1000 persons (ind chng)
ind_chng = employment_in_industry_1000*(0.014723+0.014275*GDP_change_rate-
0.00056*empl_in_ind_%)
h) Change of employment in services in 1000 persons (serv chng)
serv_chng = employment_in_services_1000*(-0.05265+0.001719*empl_in_serv_%-
0.000008303*empl_in_serv_%*empl_in_serv_%)
i) GDP change rate in EURO*10^9
GDP_change_rate = -0.06094+0.111098*EXP(-GDP_per_person/
10000)+0.00206*econ_act_pop%).

3.4.1. Validation of the model

The R^2 of the relationships given by regression equations are usually less than

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20%. However, the validation of the model, based on outputs used for calibration calculated for historical data 1995–2000, for each NUTS-x separately, avearged for EU-25 mean NUTS-x, shows quite a good match with the EUROSTAT measured data. (Table 15). The R^2 values for the relationship between modelled and measured data can be as high as 0.99, which means that algorithms used and the model itself are very robust. The measured data also fit to the linear trend, producing similarly high R^2 values, however, the period used for trend calculation is quite short, as allowed by time series of available data. Figure 8 shows how well modelled data fit the observed values – there are obvious fluctuations of measured data and sharp changes of values from year to year – e.g. for births and deaths, economically active population and employment in industry (Figure 8). The results could probably be even better if the whole model was calibrated to maximally fit all the relationships within the model, but this was beyond technical capacity at the time being, therefore the calibration is based on separate regressions only.

The data presented on Figure 9 reflects the importance of aggregation in modelling – outputs for the flows of agricultural land into urban and industrial areas aggregated at cluster level demonstrate a very close match – even summed accounts for forestry are relatively close to measured values. Although the correspondence between measured and predicted flows somewhat decreases when moving to a country level (Table 16). It is remarkable, however, that 84% and 76% of CORINE based change variability of flows of agricultural land into urban and industrial functions, respectively, are depicted by the model at this resolution level. Outliers include small countries of the size comparable or even smaller than NUTS-2 regions elsewhere. Changing the resolution to NUTS-2 level causes a decline of predictability, although still over 60% of industrial and urban land enlargement can be explained. Going down to a NUTS-x level used in this study impairs the quality of outputs. This is apparently a level where the distribution of responses to the demand for urban and industrial land is driven by local decisions, infrastructure and accessibility, as well as physical suitability and socio-economic patterns. Probably, the NUTS-x is a resolution level where a more complex

Table 15

Comparison between EUROSTAT variables trends and modelled values for mean EU-25 NUTS-x

Variable	R^2 for measured – modelled	R^2 measured – trend
Population / 1000	0.93	0.95
Births / 1000	0.72	0.69
Deaths / 1000	0.46	0.45
Economically active population [%]	0.92	0.93
Unemployment [%]	0.99	0.99
Employment in agriculture [%]	0.94	0.97
Employment in industry [%]	0.79	0.82
Employment in services [%]	0.97	0.94
GDP per inhabitant	0.99	0.98

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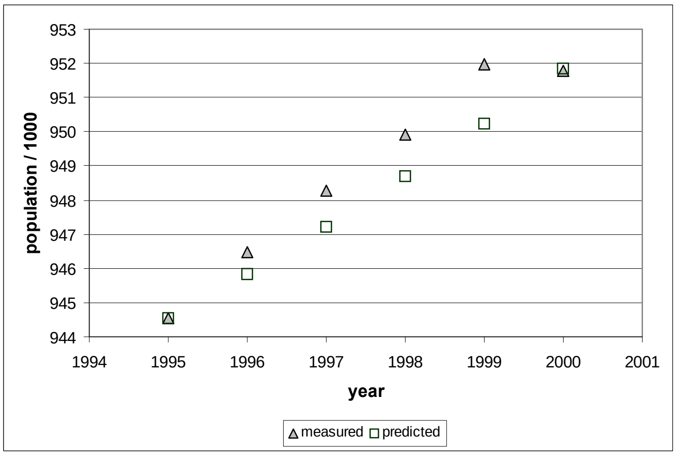

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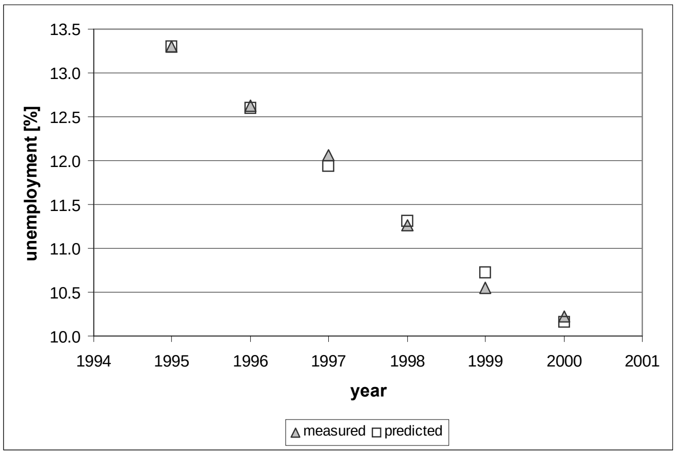

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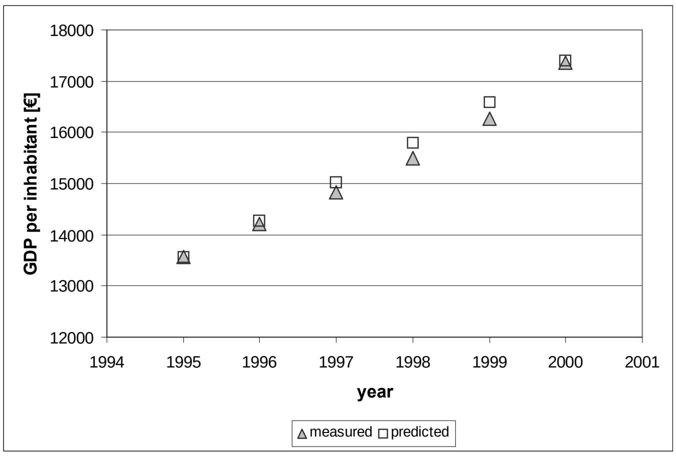

Figure 8 a, b, c. Comparison between variables predicted by the model and EUROSTAT measured data for mean EU-25 NUTS-x

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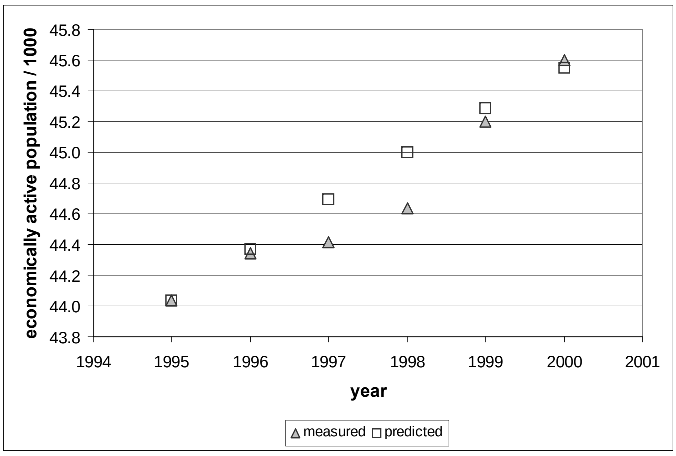

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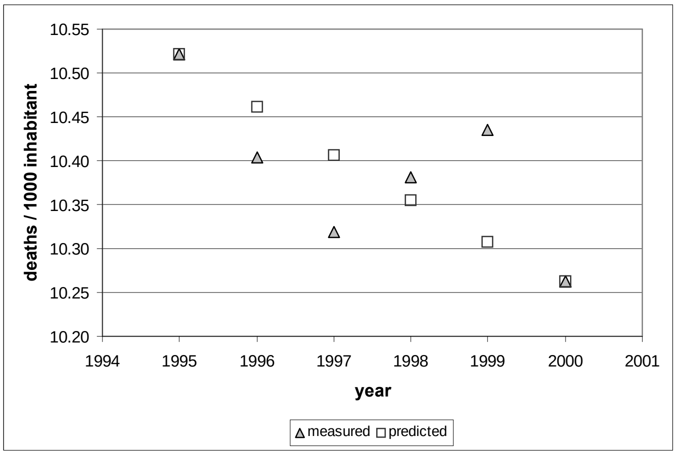

Figure 8 d, e, f. Comparison between variables predicted by the model and EUROSTAT measured data for mean EU-25 NUTS-x

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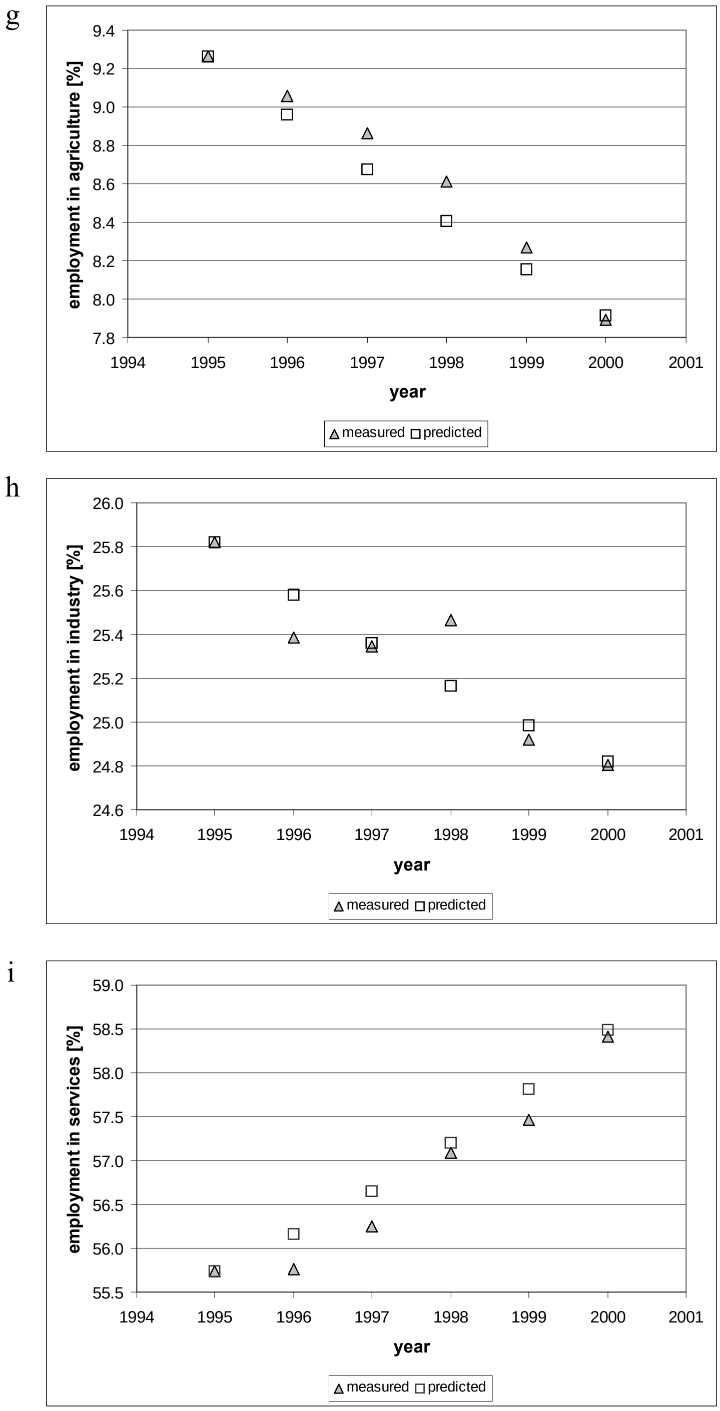

Figure 8 g, h, i. Comparison between variables predicted by the model and EUROSTAT measured data for mean EU-25 NUTS-x

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modelling framework would be needed that would take into account the local agents for a human decision component, as well as local zoning polices, attractiveness for a given function, land stocks available for a particular use, neighbourhood effects etc. Apparently, the NUTS-x is a resolution level where the combination of bottom-up and top-down approach discussed by Verburg (2006) is appropriate for disaggregating flows predicted on a country level or NUTS-2 in order to achieve meaningful results. In this sense, disaggregating is not meant as spatially explicit on a grid cell base, but concerns the allocation of flows predicted e.g. on a country level into smaller units (NUTS-x), which must be characterized by a relevant local socio-economic policy and biophysical indicators. It questionable that land use demand assessed on a country or even NUTS-2 level can be directly disaggregated into a grid. An intermediate level seems to be appropriate, but it would require an extensive input of local data, which is not accessible at the European level. Consequently, the robustness of a simplified modelling approach presented here is evident for a cluster and/or a country level. This is an important finding of this study, which suggests that predicting stocks and flows of agricultural land into other functions can be reliably done by a simple model, operating at a country or major NUTS-2 unit. The strength of this approach lies in the very limited amount of data required and the data's accessibility in a harmonized form from EUROSTAT. Its shortcomings however, have to do with local drivers, which are not accounted for in the model and disaggregating to a finer resolution is questionable.

3.4.2. Predictions of socio-economic variables driving land use change by 2020

Table 16

Assessment of impact of aggregation level on quality of modelling outputs compared to CLC measured changes 1990–2000

Agregation level	No. of units	Forest R^2	Urban R^2	Industry R^2
Clusters	5	0.77	0.99	1.00
Nuts-0 (country)	21	0.35	0.76	0.84
Nuts-1	79	0.25	0.43	0.68
Nuts-2	230	0.29	0.29	0.70
Nuts-x	411	0.08	0.33	0.41

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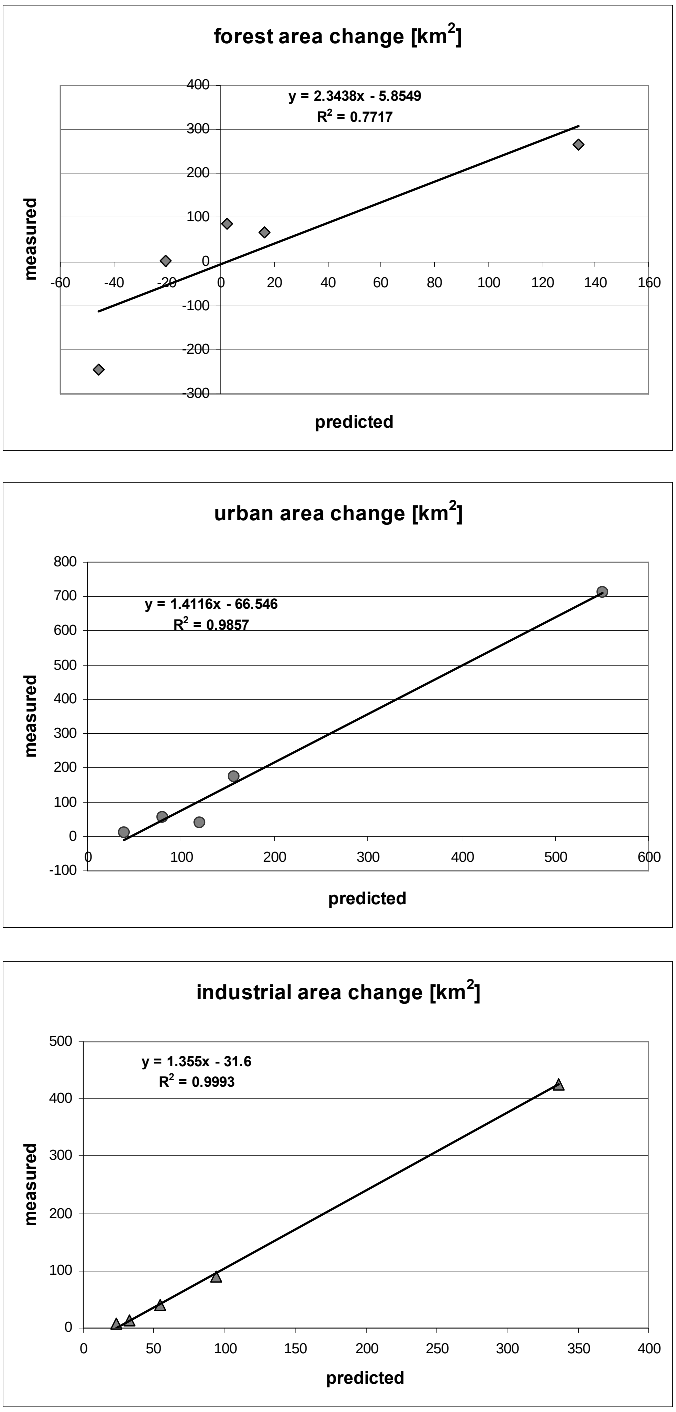

Figure 9 a, b, c. Comparison between predicted and measured agricultural land flows in 1990–2000 for five EU-25 clusters

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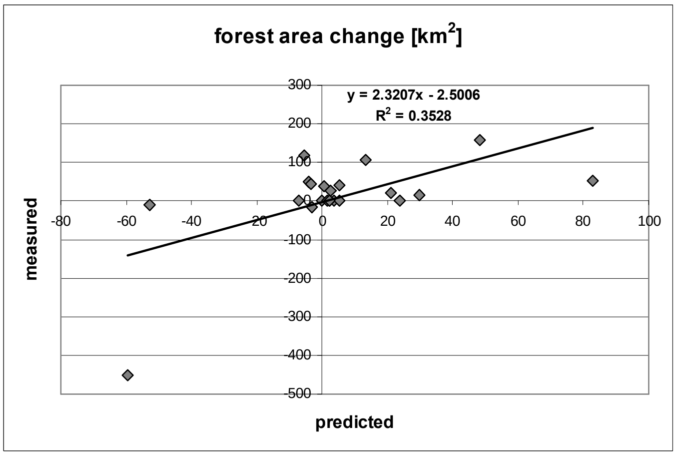

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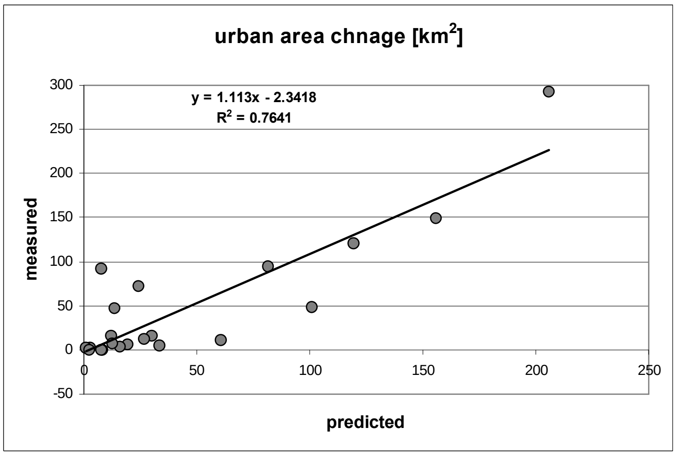

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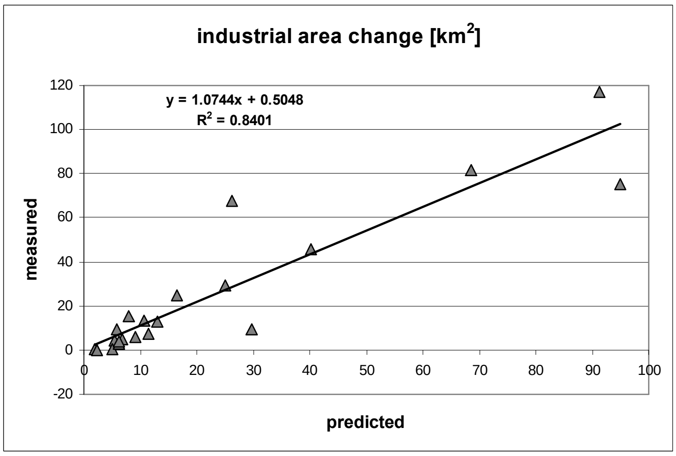

Figure 9 d, e, f. Comparison between predicted and measured agricultural land flows in 1990–2000 for country level (NUTS-0) in the EU-25

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A spatial dimension of predicted changes in selected socio-economic variables driving land use change is presented in Figure 10. Population changes, either through natural growth or by in- and out-migrations, show a continuation of a negative trend in the Central and Eastern European region, which is to be expected as a result of migration to other economically stronger regions (Figure 10). But even there, regions can be discerned that show positive population development, which is associated with their economic growth and transition.

There is quite a good agreement between the predicted population and pace of growth for an average EU-25 NUTS-x with the numbers forecasted by EURALIS in global economy and global co-operation scenarios (Westhoek et al., 2006). Comparing the predictions, after standardizing data - with EUROSTAT (2006) forecasts shows that the increase in population is faster, although by 2020 the numbers do not differ significaantly.

Presented predictions correlate quite well in terms of regional trends with SCENAR predictions (Nowicki et al., 2007), which also show increasing population developments in South-Western Europe, Ireland, the UK, and southern Sweden. The strongest increase of population predicted by SCENAR is expected in selected regions of Spain and Ireland, which experience very strong economic development in the 1990s. – this is in agreement with the predictions presented here for Ireland, but not for Spain. However, considering the economically active population, both countries demonstrate a strong increase (Figure 10). Population predictions generated in this study for the Baltic States disagree with that of SCENAR, which predicts a visible increase and not stagnation. Negative changes of population and other socio-economic parameters, observed in some regions should be interpreted as stagnation rather than a decline, as the model does not aim at predicting future developments in a sense of 1:1 relation for each NUTS, but rather at indicating major spatial trends. It is obvious that considering population stagnation in Europe, a positive demographic development in some regions results from in-migration. Similarly, spatial trends in changes of the economically active population should be interpreted as indicative of stagnating or developing regions - there is a clear increase observed in western and southern Europe. Surprisingly, predictions for the UK are indicating no change relative to the year 2000. Interestingly, there are regions in the New Member States (EU-10), particularly in Poland, Slovakia, and the Baltic States, which are performing well economically, and there is a strong increase in the economically active population (Figure 10). These regions attract investment and employment, which is translated into predicted numbers.

The predicted relative growth of GDP per inhabitant is the highest in the EU-10 (>300%), followed by Portugal, a major part of Spain, Greece and eastern Germany (150-300%). Regions in southern Italy, the UK, southern France, Belgium, Netherlands, Denmark and a major part of Sweden represent an intermediate group of GDP increase (120-150%) – Figure 10. Most of Germany, France and Italy exhibit an increase in a range of 100-120%. An absolute increase of GDP counted in EURO per inhabitant shows a different distribution, reflecting the size and strength of the economy (Figure 10). The largest increases are observed in regions of the UK, Netherlands, Denmark, Sweden and Finland – this also includes major European metropolitan cities.

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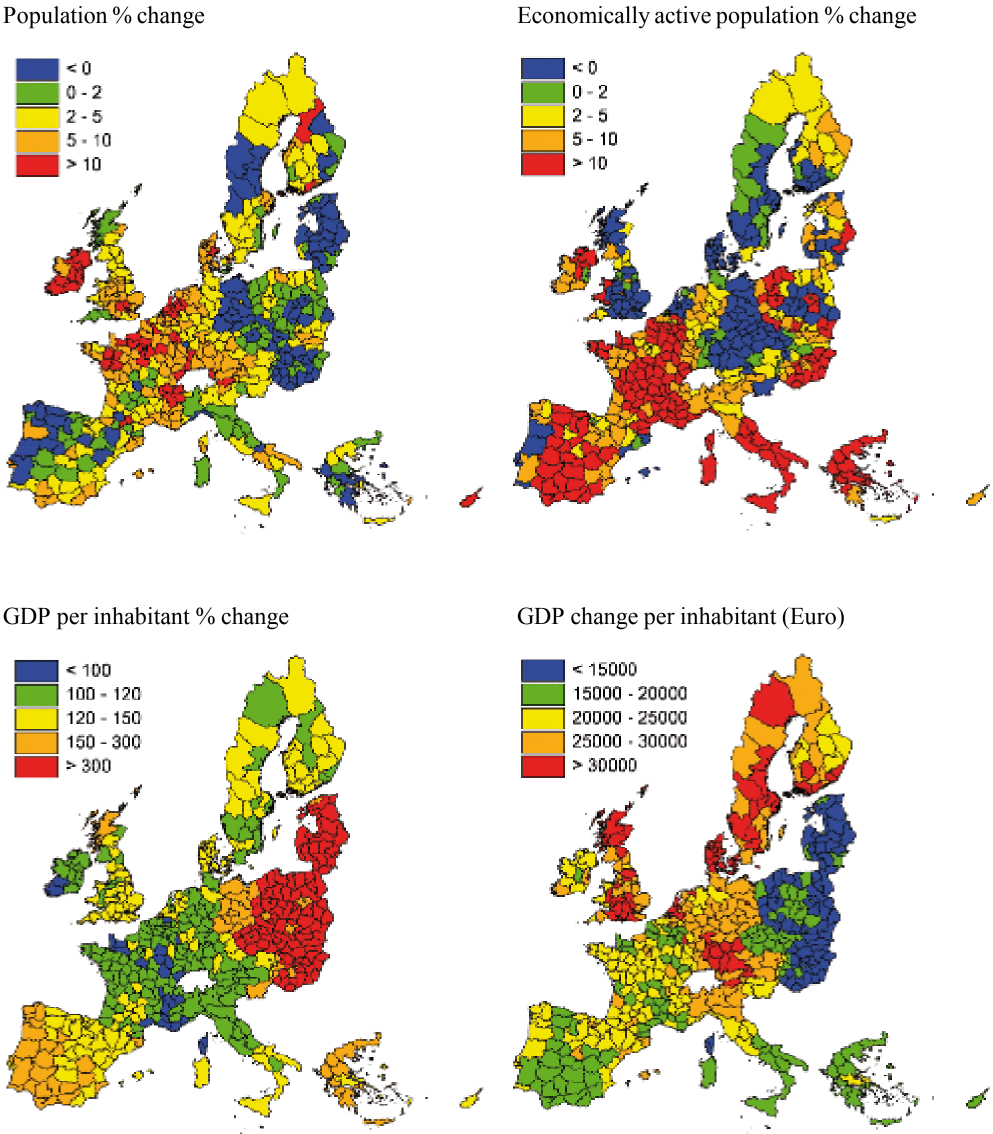

Figure 10. Predictions of population and GDP for EU-25 by 2020

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3.4.3. Outputs of dynamic land use modelling for 2020

As noted previously, modelled values of socio-economic variables fit quite well to the EUROSTAT measured data and trends for 1995–2000. However, a running model for the period extended to 2020 shows that with time, the values of modelled data become quite different, as compared to an extended trend (Figure 11). This behaviour is a result of system dynamics and associated feedback. The predictions demonstrate non-linear shape plotted for time for an average EU-25 NUTS-x unit. Thanks to model dynamics, the behaviour of variables is probably more realistic than that predicted from trends – e.g. GDP grows faster than expected from a trend, whereas the economically active population grows slower and the rate of its change declines with time (Figure 11). Particularly important differences concern: modelled unemployment and employment in agriculture, which are declining at a much slower pace than predicted by trends. In contrast, employment in services grows faster than those predicted from a trend.

It is worth mentioning that 2000–2004 EUROSTAT data are added to plots, and in most cases the agreement with the modelled values, except population, is very good. It is likely that 2000–2004 data for population is not verified yet, or the methodology of data collection was changed. It is a common practice in statistical surveying that recent data published are of preliminary nature, being subject to later corrections and updates (Welfe & Welfe, 1996).

Predictions for different land use functions until 2020 for an average EU-25 NUTS-x unit are demonstrated on Figure 12, together with a trend line drawn based on a CORINE 1995–2000 change layer. It is remarkable that agricultural land decline follows the trend line until 2010, and then it decreases at a visibly faster pace, relative to that

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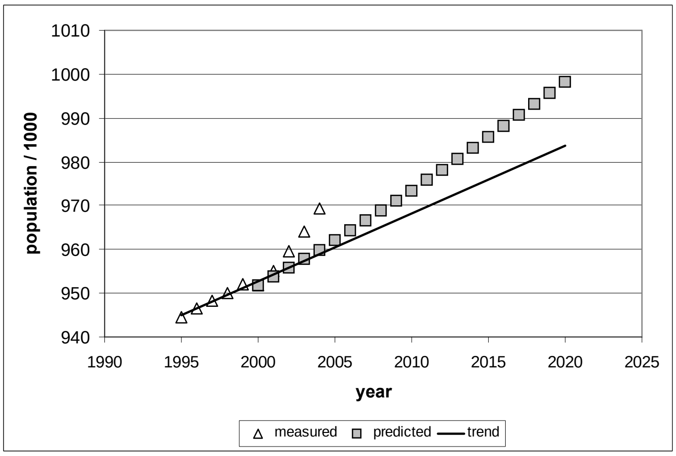

Figure 11 a. Prediction of socio-economic variables and their linear EUROSTAT trends until 2020 for an average EU-25 NUTS-x

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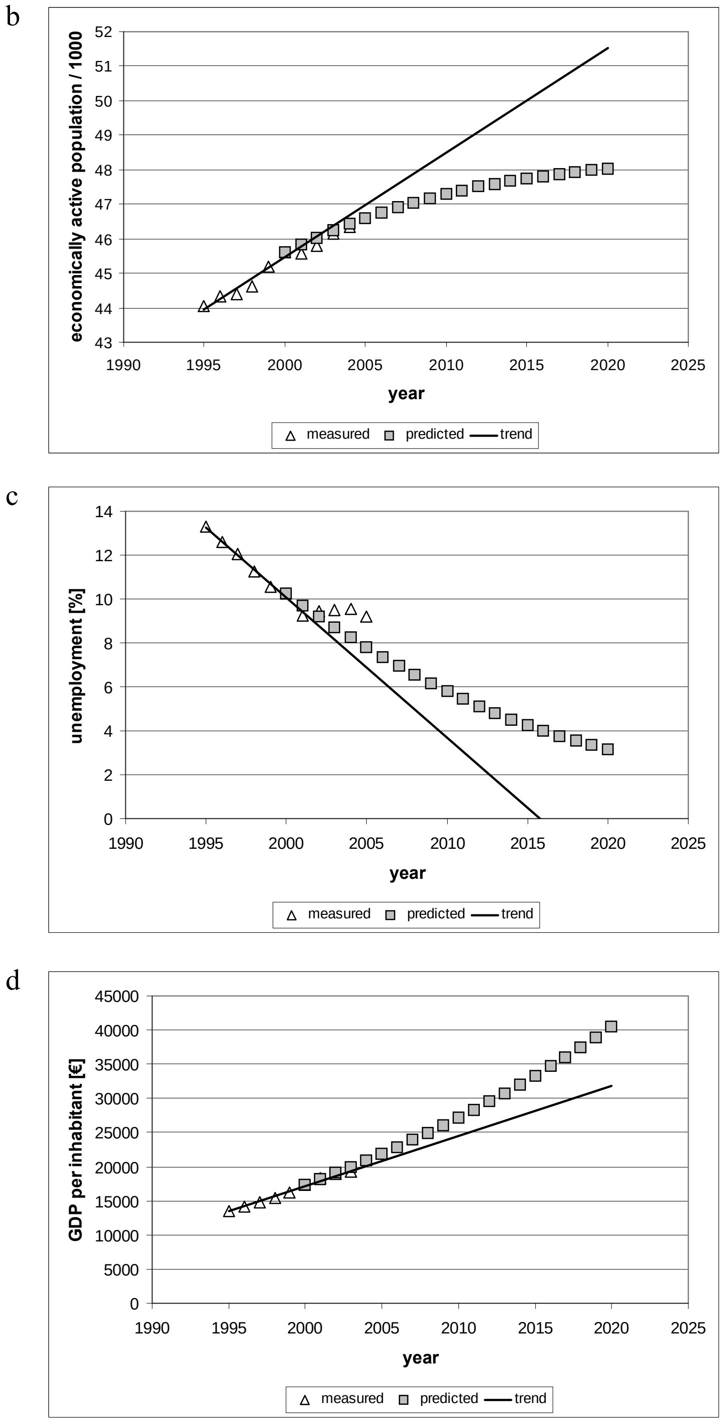

Figure 11 b, c, d. Prediction of socio-economic variables and their linear EUROSTAT trends until 2020 for an average EU-25 NUTS-x

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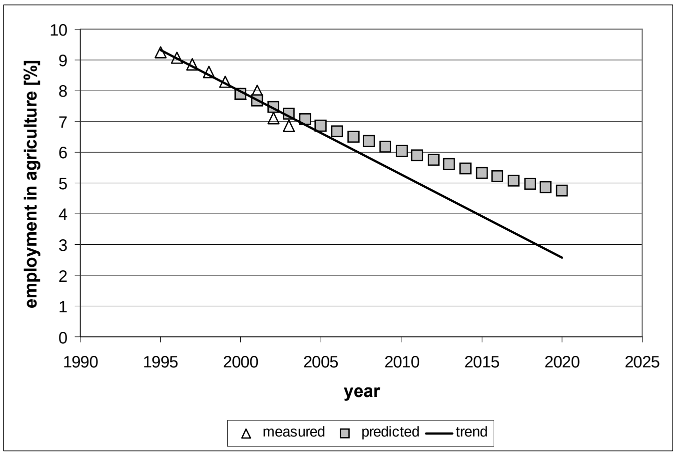

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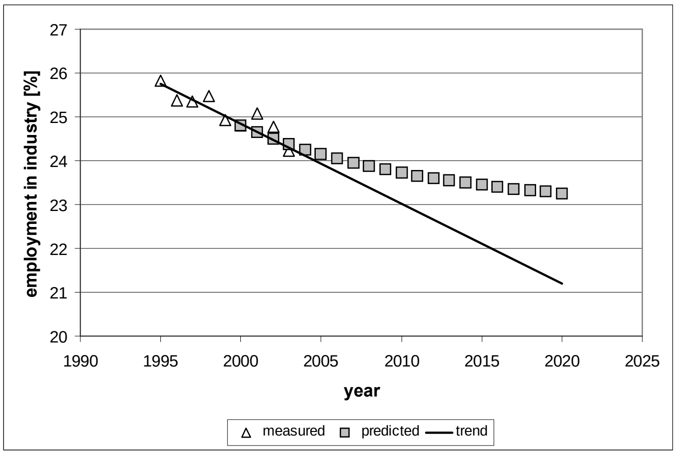

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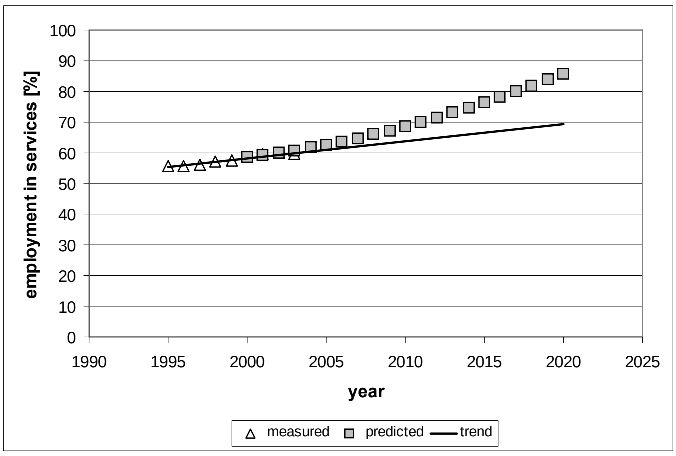

Figure 11 e, f, g. Prediction of socio-economic variables and their linear EUROSTAT trends until 2020 for an average EU-25 NUTS-x

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indicated by the trend line (Figure 12). This is due mainly to the flows into forests and semi-natural areas. Changes of forests and semi-natural areas are very different from the trend – predictions show that from 2010 on, the rate of forest expansion at the expense of agricultural land will be considerably higher than in the earlier period. With regards to forest change predictions, it is important to mention, that they are rather uncertain, as the historical changes in 1995–2000 were not satisfactorily explained by multiple regression equations based on which land use model calculates the outputs. As discussed before, the R^2 for these relationships were very poor, often not exceeding 10% and the probable reason is that changes in the forest area are not only driven by socio-economic variables used in the model, such as GDP, or population and employment parameters, but respond to a country-specific policy of forestation and natural constraints for agricultural production on marginal land. Another important reason could be the uncertainty of the CLC change layer, as only changes larger than 5 ha and with the width of >100 m were recorded (EEA, 2006b). In fact, a scattered nature and diverse structure of land use in countries such as Poland, where forestation takes place on small parcels often not forming major complexes, may not be depicted as a change. In consequence, forest area change measured based on this layer can be affected by a substantial error. A noise in historical land use data and a weak response of forest area to changes in socio-economic variables should be taken into account when interpreting the distribution of changes in NUTS-x grid throughout the EU-25 (Figure 12).

Interestingly, predictions for urban and industrial areas of an average EU-25 NUTS-x are in good agreement with CLC 1990-2000 based trends – predictions are only slightly higher from the year 2012 on – Figure 12. Summary data for predicted changes of forest and semi-natural areas, urban, commercial and industrial land is presented in

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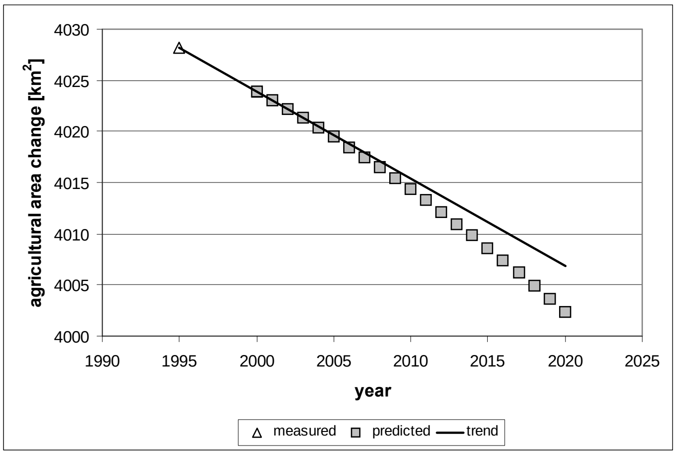

Figure 12 a. Dynamic model predicted land use data and linear trends until 2020 for an average EU-25 NUTS-x

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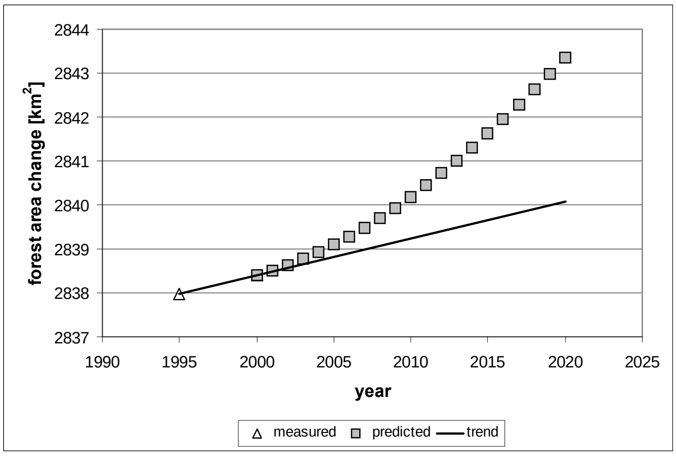

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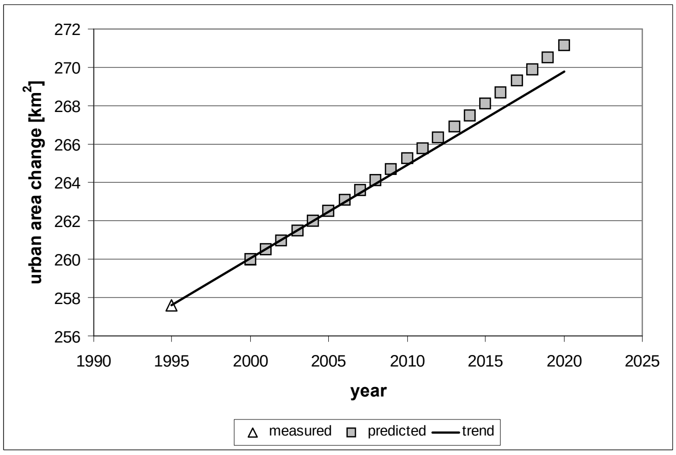

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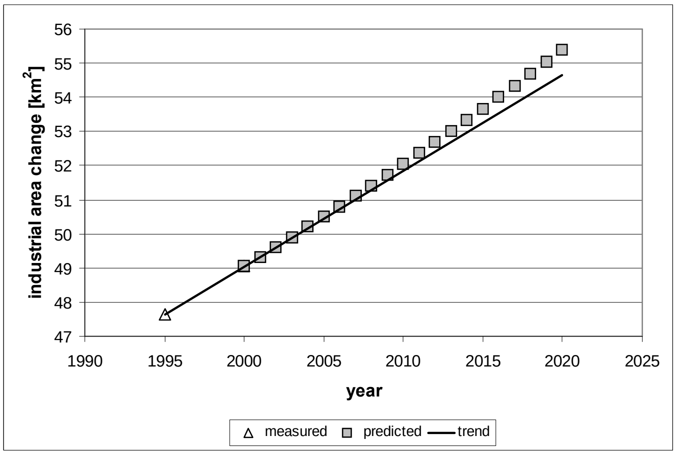

Figure 12 b, c, d. Dynamic model predicted land use data and linear trends until 2020 for an average EU-25 NUTS-x

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Tables 17-19. The data is aggregated for five clusters, which does not show the variability of change relative to the year 2000 within each cluster. As shown on maps for NUTS-x grid (Figure 13), there is considerable variability across Europe in flows from agricultural land into forest, urban, commercial and industrial functions.

As mentioned before, the model does not have any settings to account for urban planning policies and resulting differences in attractiveness for investment or urban development of a region, therefore the spatial allocation of the built-up area may be different than projected, although regional trends should be quite accurate.

Predictions for forest and semi-natural areas are the most uncertain results of modelling, as the R^2 describing the relationship between socio-economic variables was very poor. It is apparent that conversion of agricultural land into forests or semi natural areas is controlled rather by suitability conditions, local policies, and local organization and production patterns – factors operating on a micro level – and not necessarily by parameters describing economic growth, employment and population. It seems that the main driver of conversion is the land's low suitability for agriculture, which can not efficiently utilize a marginal land and as a consequence it moves into semi-natural areas or is converted into a forest – this process is prompted by policy instruments of the Rural Development Plan. Nevertheless, these policy variables and land suitability were not considered in the model, as it was beyond this research's objectives. An important conclusion is that the area of European forest is more or less stagnating and in most regions changes are ranging between - 0.5% to -0.5%, relative to 2000. Negative values should not be quoted as indicative of decline but stagnation – this concerns a major part of Poland, Slovakia, the Baltic States, Finland, Greece, and some regions in Spain (Figure 13). Most of the EU-15 show an increase in forest and semi-natural areas. SCENAR predictions, in some scenarios, forecast an increase of forest in southern France, Italy and the north-west of the Iberian Peninsula, which is mainly driven by a succession from areas that are currently under semi-natural vegetation. Comparisons are difficult, as predictions in SCENAR are run purely for forests, whereas here, forests and semi-natural areas are treated together. In the baseline and regionalization scenarios of SCENAR, Latvia and Lithuania show a decrease in forests, because of an increase in arable land – although it seems rather unlikely, as there is no particular pressure of agriculture competing with forestry for a space, considering the vast areas of abandoned land in the Baltic States (Petersom & Aunap, 1998). Keeping in mind the fundamental weaknesses of modelling forest change, a more involved analysis would be of a speculative nature, and the only important conclusion is that there will probably be positive trends developing in the future in most of the EU, with a possible stagnation in eastern regions, although local policies under RDP may become a driving force for marginal land forestation. It is worth noting, however, that in SCENAR 2020, the scenario projections for 2020 do not show much difference between various socio-economic settings, regarding forest growth. This is explained by the fact that forests require a long period to grow, and are therefore less vulnerable to differences in policy scenarios (Nowicki et al., 2007).

The growth of urban and industrial areas is shown on Figure 13 relative to 2000

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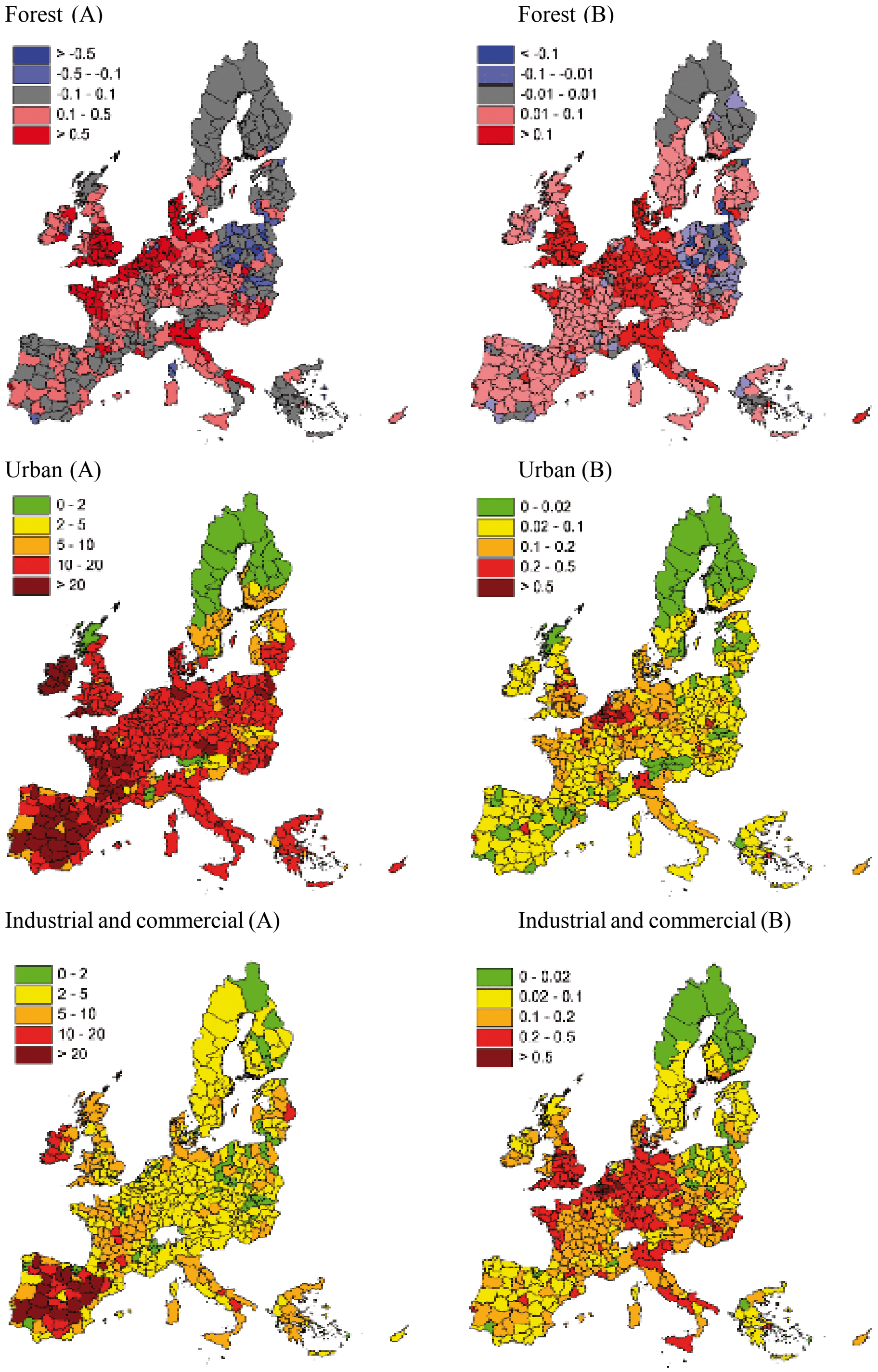

Figure 13. Model predictions of changes in forest, urban and industrial areas – (A) % relative to their initial size in 2000, (B) % relative to the total NUTS-x area

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and as a percentage change relative to their size in the total NUTS area. This helps to better visualize the progress in development, which is much larger relative to 2000 in countries like Spain, as compared to Germany (Figure 13). However, assessing the acreage taken by urban development and industry, relative to the total NUTS area, demonstrates that regardless of lower dynamics, area wise the loss of agricultural land will still be larger in Germany (Figure 13). There is a remarkable difference in the pattern of agricultural land conversion into urban and industrial functions in comparison to the area occupied by these functions in 2000 (Figure 13). There is not that much pressure on urbanization in Central and Eastern Europe, although some contrasts can be observed in these regions. A strong increase of land consumption by urbanization is predicted for Spain and Ireland, followed by France, Italy, Greece, Denmark, and the Baltic States – some regions in Poland also fall into this category (Figure 13). Industrial areas will increase remarkably, particularly in Spain, Ireland France and some regions in Poland (Figure 13).

In terms of acreage consumed by urbanization, the largest flows (relative to the total region area) are predicted for the French coast, southern UK, parts of Italy, Netherlands Belgium and a major part of Germany (Figure 13).

The largest increases of industrial functions, size-wise, are expected in northern regions of Germany, Netherlands, the UK and in a few Eastern European regions (Figure 13). This is indicative of demand for industrial and commercial land, which will still be the largest in the EU-15, so far consuming most of the direct investment. A significant amount of agricultural land will also be converted into industrial functions in regions along the French coast and in northern Italy. As discussed before, conversion to urban or industrial functions is not driven by a single factor, and the dynamics of this process may be region-specific, as shown by the results of descriptive statistics for the five European clusters. Comparing predictions for urban and industrial land change combined together produces a similar spatial trend to that projected by SCENAR 2020 under the liberalization scenario (Nowicki et al., 2007).

When discussing land use changes generated by the model, it is important to keep in mind that an analysis of historical CLC data is the foundation of relationships used to build model algorithms. The magnitude of a change observed in the past is subjected to some uncertainty of the change layer – according to an official report on CORINE 1990–2000 exercise, there is insufficient detection of small changes, particularly those associated with the estimates of stock and change, mainly for artificial surfaces and urban development, which can be therefore underestimated (EEA, 2006b). As a result, there may be a bias in the estimates of stock and change, mainly for artificial surfaces. Regarding forest accounts within clusters, the largest increase relative to stock in 2000 is predicted for the western cluster 4 (0.43%). Relatively small increases of forest stocks are forecasted in cluster 1 and 3, whereas clusters 2 and 5 exhibit stagnation, or even a slight decline (Table 17). Even though the accuracy of the model for forest cover is quite limited for NUTS-x level, and therefore the distribution pattern is not very reliable, predictions aggregated to clusters may be realistic, as proven in the

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validation step, where as much as over 70% of forest change in the period from 1990 to 2000 was explained by the model. However, as stressed before, socio-economic drivers do not necessarily retrieve mechanisms of forest evolution, and on the regional level, biophysical parameters and polices play a major role, and would need to be included in the modelling framework.

Predicted trends in development of industrial areas are very similar to these of urban growth (Table 19). The largest increase of industrial and commercial areas, relative to their size in 2000, is expected in the southern cluster 3 (15%), followed by the western, economically strong cluster 4 (13%). A slightly smaller increase is predicted for the rural cluster 2 – 12.6% and 11.3% relative to the year 2000. Relatively to the total area, the most sizeable change will concern the western cluster 4, and it will be at least twice as large as in other clusters. Similarly to urban development, it is rather surprising that an expansion of industrial and commercial areas in the economically weak industrial cluster 1 and the rural cluster 2 will be so small, both in relation to their initial size, as well as relative to the total cluster area. GDP in these clusters will grow at a much faster pace than in the western clusters, but the size and strength of the economy will be still considerably smaller. In consequence, the pressure on agricultural land in the western clusters, comprised mostly of former EU-15 countries, will continue to be much stronger as compared to the new member states. It seems that the size and type of economy has a much bigger impact on this pressure than the physical availability of land and the attractiveness of lower prices on the land market. The size of western economies will continue to generate a much bigger demand for urban and industrial commercial land than it is expected in most of the regions in the new member states covering a majority of cluster 1 and 2 (Table 18, 19).

Table 17

Predicted changes in forest areas in clusters at the expense of agricultural land by 2020

Cluster	Total area [km^2]	Forest (f) 2000 [km^2]	Change (d) [km^2]	d/f 2000 [%]	d/total area [%]
1	595326	256951	241	0.09	0.04
2	380034	134032	-59	-0.04	-0.01
3	747716	323253	324	0.10	0.04
4	1272105	353566	1523	0.43	0.11
5	968290	712348	231	0.03	0.02

Table 18

Predicted changes in urban areas in clusters at the expense of agricultural land by 2020

Cluster	Total area [km^2]	Urban (u) 2000 [km^2]	Change (d) [km^2]	d/u 2000 [%]	d/total area [%]
1	595326	13786	601	4.4	0.10
2	380034	9313	319	3.4	0.08
3	747716	13903	840	6.0	0.11
4	1272105	65362	2707	4.1	0.21
5	968290	16075	438	2.7	0.04

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Table 19

Predicted changes in industrial areas in clusters at the expense of agricultural land by 2020

Cluster	Total area [km^2]	Industrial (i) 2000 [km^2]	Change (d) [km^2]	d/i 2000 [%]	d/total area [%]
1	595326	2868	326	11.3	0.05
2	380034	1503	190	12.6	0.05
3	747716	3180	478	15.0	0.06
4	1272105	1232	1609	13.0	0.12
5	968290	3061	211	6.9	0.02

3.5. ASSESSMENT OF LAND USE CHANGE IMPACT ON SOIL FUNCTIONS

3.5.1. Land suitability

Land suitability varies greatly across Europe, which is shown on the map (Figure 14). It seems that the distribution of potential productivity is driven strongly by climate, as the least productive lands are localized in southern Europe, which is characterized by high evapotranspiration, and in Scandinavian regions, where low temperature is a limiting factor. Soils play an important role in controlling water balance and have a visible impact on land suitability in Central and Eastern Europe.

The assessment of land use changes within clusters in the context of land suitability varies. Clusters are different in size and therefore it is not practical to compare, between clusters, total area changes, but rather to interpret transition indexes of different land suitability classes.

The industrial, economically and socially week cluster 1 is quite balanced in terms of management of good quality land – even though in absolute numbers, the largest areas of arable land converted into artificial surfaces represent medium land suitability (24,191 ha, 78.35% of arable land converted) – this change is proportional to the share of this class in the total arable land area (transition index 1.02) – Table 19. It is remarkable and rather detrimental that as much as 5496 ha of a pasture land were converted into artificial surfaces within this cluster – which is more than 20% relative to arable land consumed by built-up areas. Pastures on highly suitable land are preferentially converted into forests and semi-natural areas within this cluster – transition index 2.33 (Table 20). The same concerns the conversion of highly suitable arable land into forests – conversion index 1.57. Similarly, an increase of artificial surfaces at the expense of high quality pasture land is also strongly preferential – transition index 2.04. Transition of agricultural land (arable and pasture) into other classes, either forests or artificial surfaces, takes place mainly on medium quality land – usually about 70% of all transitions occurred within this class, although it is reflecting a share of this suitability class in the total area of arable and pasture land. In general,

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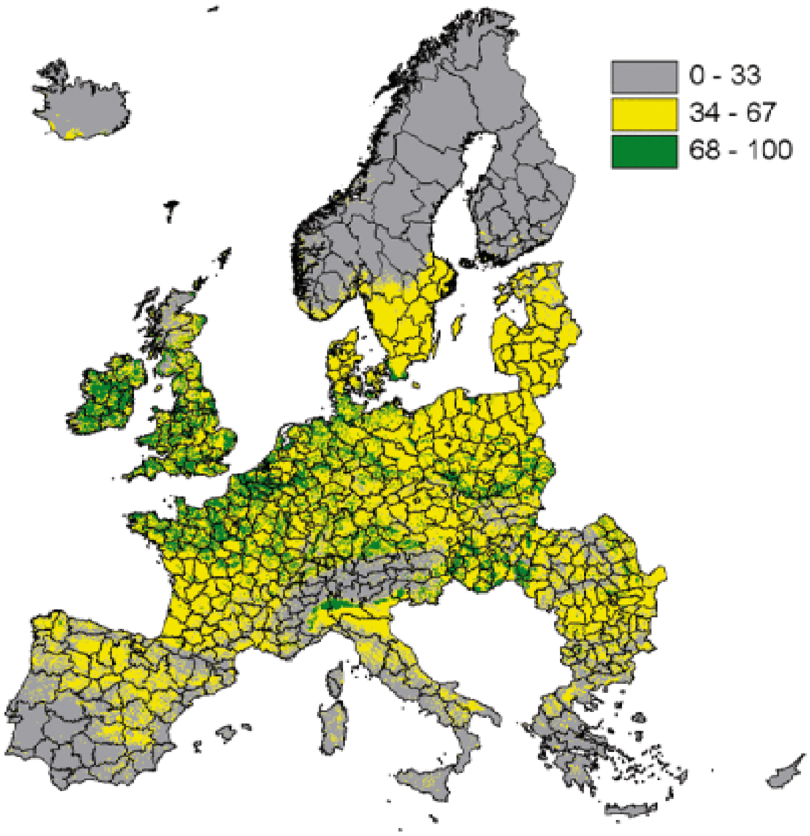

Figure 14. Distribution of land suitability throughout the EU-25

with regards to land suitability, flows of agricultural land are mostly sustainable, except the preferential conversion of good pasture land into artificial surfaces.

Rural, economically and socially weak cluster 2 is characterized by an efficient management of low-suitability arable land, which is preferentially converted into forests and semi-natural areas, at a rate more than three times higher than expected from the LS general pattern – transition index 3.46 (Table 21). Medium and high suitability arable land seems to be well protected by agricultural management and its conversion into forests is proportional. Very intense conversion into forests occurred on low suitability pasture land, which is indicated by a high transition index – 14.01. In absolute numbers, a much larger acreage of medium suitability land was converted in to forests (7746 ha). However, this is a non-preferential flow following land suitability structural pattern, as indicated by transition index (0.79). A conversion of different land suitability classes into artificial surfaces is quite balanced within this cluster. Transition indexes for low and medium suitability arable land flows into artificial surfaces are close to 1, and that for high LS is 0.71, which is indicative of sustainable use of

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Table 20

Transition indexes and shares of land suitability in various land use conversion types in cluster 1

Conversion type		Low LS (<34)	Medium LS (34-67)	High LS (>67)
Arable land into Forest and semi natural areas	ha	1595	18525	6248
	%	6.05	70.26	23.70
	transition index	0.76	0.91	1.57
Pastures into Forest and semi natural areas	ha	1775	9518	2569
	%	12.80	68.66	18.53
	transition index	1.34	0.83	2.33
Arable land into Artificial areas	ha	1934	24191	4751
	%	6.26	78.35	15.39
	transition index	0.79	1.02	1.02
Pastures into Artificial areas	ha	856	5496	1228
	%	11.29	72.51	16.20
	transition index	1.18	0.88	2.04

arable land resources. It is noticeable that the index for pasture low suitability land transition into artificial areas is high (2.85), although total pasture areas converted within this LS class is 90 ha only. Much more medium land suitability pastures were converted (1046 ha) but it was proportional to the share of this LS in the pasture land structure. Concerning LS, the overall assessment of land conversion in cluster 2 is rather positive.

Within the southern, economically and socially weak cluster 3, the management of medium and high suitability land is rather sustainable, as most of the flows occurred on low suitability arable or pasture land. Usually between 60% and 86% of all flows took place on low suitability land, except conversion of pastures into artificial areas, of which 72.64% belong to medium quality land. The transition of pastures into forests is particularly intense, as reflected by a high transition index – 2.34. The consumption of arable land by artificial areas on different suitability classes reflects their structural pattern within the entire arable land area. A preferential flow of pastures on medium quality land is a negative aspect of land management in this cluster.

Within the economically strong, western cluster 4, which groups rich, Northern European economies, forestation takes place mainly on medium and high suitability arable and pasture land – this regards over 95% of arable and 88% of pasture land afforested. Similarly, built-up areas on arable and pasture land mainly consumed medium and high quality land – over 97% of the expansion of artificial surfaces on arable and pasture land occurred on these suitability classes. It is important to stress that within this cluster such land dominates, and there is no other option for meeting development demands. Nevertheless, the indexes of transition of arable and pasture land

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Table 21

Transition indexes and shares of land suitability in various land use conversion types in cluster 2

Conversion type		Low LS (<35)	Medium LS (35-70)	High LS (>70)
Arable land into Forest and semi natural areas	ha	2492	9099	457
	%	20.68	75.52	3.79
	transition index	3.46	1.00	0.20
Pastures into Forest and semi natural areas	ha	3939	7746	303
	%	32.86	64.61	2.53
	transition index	14.01	0.79	0.16
Arable land into Artificial areas	ha	939	11442	1918
	%	6.57	80.02	13.41
	transition index	1.10	1.06	0.71
Pastures into Artificial areas	ha	90	1046	208
	%	6.70	77.83	15.48
	transition index	2.85	0.95	0.96

for these suitability classes are close to 1. Therefore their loss represents a respective share in the land cover.

In cluster 5, which includes major metropolitan areas, there is a strong pressure on arable and pasture land, being preferentially converted into artificial areas. Urban growth on arable land was at the expense of medium and high quality land, as indicated by high values of transition indexes – 2.30 and 3.27, respectively. Relatively large areas of pasture land were transformed into artificial surfaces, coming to over 55% of the arable land converted into this land use function. This loss is equally distributed among low, medium and high suitability pastures. Pressure on pasture land is much stronger here relative to other clusters. Potentially, this may have a negative impact on biodiversity.

Table 22

Transition indexes and shares of land suitability in various land use conversion types in cluster 3

Conversion type		Low LS (<35)	Medium LS (35-70)	High LS (>70)
Arable land into Forest and semi natural areas	ha	70618	11297	3
	%	86.21	13.79	0.00
	transition index	1.33	0.39	0.02
Pastures into Forest and semi natural areas	ha	2024	1296	40
	%	60.24	38.57	1.19
	transition index	2.34	0.72	0.06
Arable land into Artificial areas	ha	39419	23550	146
	%	62.46	37.31	0.23
	transition index	0.97	1.06	1.38
Pastures into Artificial areas	ha	1093	4140	466
	%	19.18	72.64	8.18
	transition index	0.74	1.35	0.40

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Table 23

Transition indexes and shares of land suitability in various land use conversion types in cluster 4

Conversion type		Low LS (<35)	Medium LS (35-70)	High LS (>70)
Arable land into Forest and semi natural areas	ha	783	23402	10860
	%	2.23	66.78	30.99
	transition index	0.63	1.07	0.90
Pastures into Forest and semi natural areas	ha	3162	12753	10597
	%	11.93	48.10	39.97
	transition index	3.80	0.92	0.90
Arable land into Artificial areas	ha	6275	170563	111963
	%	2.17	59.06	38.77
	transition index	0.61	0.95	1.13
Pastures into Artificial areas	ha	1663	59993	46421
	%	1.54	55.51	42.95
	transition index	0.49	1.06	0.97

Table 24

Transition indexes and shares of land suitability in various land use conversion types in cluster 5

Conversion type		Low LS (<35)	Medium LS (35-70)	High LS (>70)
Arable land into Forest and semi natural areas	ha	10	246	253
	%	1.96	48.33	49.71
	transition index	0.03	1.98	3.94
Pastures into Forest and semi natural areas	ha	1114	1680	937
	%	29.86	45.03	25.11
	transition index	0.84	106	1.15
Arable land into Artificial areas	ha	236	5113	3762
	%	2.59	56.12	41.29
	transition index	0.04	2.30	3.27
Pastures into Artificial areas	ha	1640	1814	1631
	%	32.25	35.67	32.07
	transition index	0.90	0.84	1.47

3.5.2. Land use change and soil water retention capacity

The retention of water by soils plays an important role in controlling the growth of biomass and the soil's biological functions, but it is also a key factor in regulating water movement and storage within landscapes. An increase of impervious surface can alter the natural hydrologic condition within a watershed (Tang et al., 2005), and ac-

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celerate runoff (Moscrip & Montgomery, 1997), increasing chances for local flooding (Field et al., 1982).

In a perspective of climate changes and extreme events, such as heavy rainstorms and flooding, preserving storage capacity plays a key role in the mitigation of impacts. Therefore, it is crucial that urban and infrastructure development avoid areas of high water retention capacity. Distribution of water retention capacity across Europe is demonstrated on the map (Figure 15), as the total available water in millimeters, assuming 1 m as soil profile depth. It is worth mentioning that it differs significantly from the distribution of land suitability. Water retention is important for land suitability, but climate may play even bigger role – the impact of climate is particularly important in Southern European regions, where water retention is high, but overall land suitability is extremely low. In the assessment, the preferential conversion of high retention capacity soils into artificial areas is interpreted as a negative process, whereas afforestation of low retention capacity soils is generally considered as a positive contribution to improving water storage in landscapes.

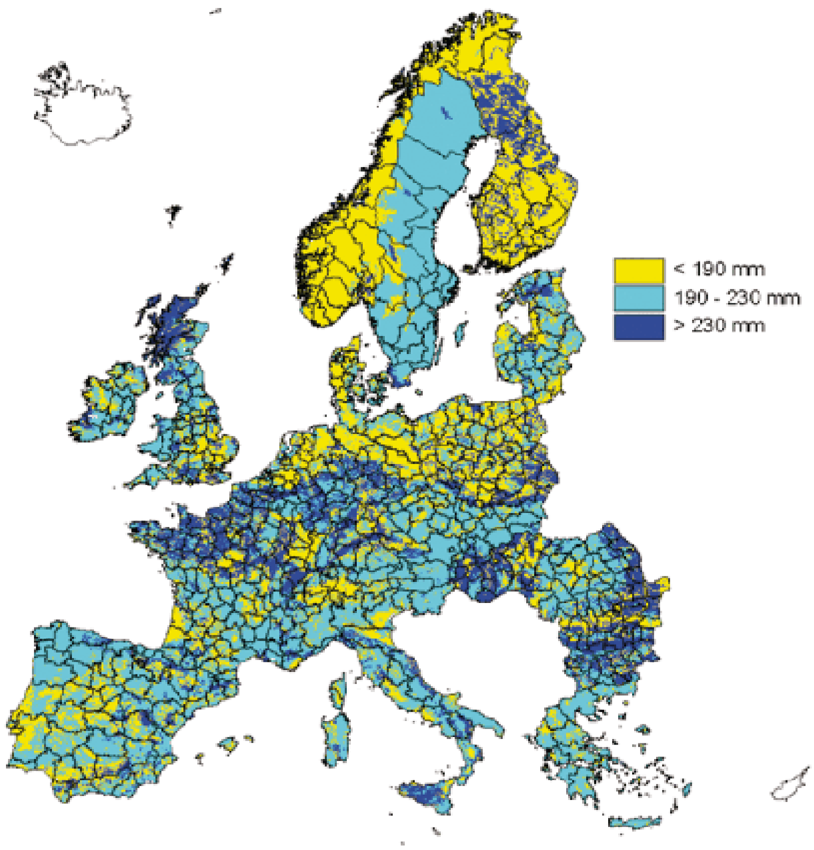

Figure 15. Distribution of water retention in soils to a depth of 1 m (based on European soil map)

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In the industrial, socially and economically weak cluster 1, the vast majority of arable and pasture land flows into forests took place on medium and high retention capacity soils (Table 25). A strongly preferential conversion of high retention soils is observed on pastures changing into a forest – conversion index 3.15. Medium and high retention pasture soils converted into forests have a similar share in the total pasture area transformed – 42.69 and 38.78%, respectively. It is remarkable that a majority of urbanized arable and pasture land represent medium or high retention capacity. Within arable land, the transition index for these retention classes is 1.15 and 0.74, which is indicative of a more or less proportional conversion, relative to their share in the total arable land – Table 25. Within pasture land, however, high retention soils are preferentially converted into artificial areas, (transition index 1.99), which is a negative aspect of land management in this cluster.

In cluster 2, which is more rural in nature than the other regions, high retention soils are usually excluded from conversion into forests – this seems to suggest that their high value for agriculture provides an efficient protection against changes into other functions. Similarly, a very limited acreage of high retention arable and pasture soils, on total and percentage bases, was consumed by urbanization. Almost 60% of arable land converted into artificial surfaces displays low retention capacity and the conversion index is 1.36, which indicates a preferential conversion of this class. Consequently, the scale of conversion of medium and high retention arable land is considerably smaller than the contribution of these retention classes in the total arable land area – conversion indexes are 0.76 and 0.64, respectively.

Within the southern economically and socially weak cluster 3, as opposed to the rural cluster 2, most of forestation of arable land took place on soils of medium retention (65.8%). A similar pattern concerns the conversion of pasture land into forests, which

Table 25

Transition indexes and shares of soil water retention capacity classes in various land use conversion types in cluster 1

Conversion type		**Low retention (<190 mm)**	**Medium retention (190-230 mm)**	**High retention (>230 mm)**
Arable land into Forest and semi natural areas	ha	9314	8638	8416
	%	35.32	32.76	31.92
	transition index	1.41	0.62	1.47
Pastures into Forest and semi natural areas	ha	2569	5918	5375
	%	18.53	42.69	38.78
	transition index	0.74	0.68	3.15
Arable land into Artificial areas	ha	6974	18919	4983
	%	22.59	61.27	16.14
	transition index	0.90	1.15	0.74
Pastures into Artificial areas	ha	1449	4288	1843
	%	19.12	56.57	24.31
	transition index	0.76	0.90	1.98

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Table 26

Transition indexes and shares of soil water retention capacity classes in various land use conversion types in cluster 2

Conversion type		Low retention (<190 mm)	Medium retention (190-230 mm)	High retention (>230 mm)
Arable land into Forest and semi natural areas	ha	7616	3665	767
	%	63.21	30.42	6.37
	transition index	1.45	0.88	0.29
Pastures into Forest and semi natural areas	ha	3026	8633	329
	%	25.24	72.01	2.74
	transition index	0.49	3.58	0.10
Arable land into Artificial areas	ha	8525	3786	1988
	%	59.62	26.48	13.90
	transition index	1.36	0.76	0.64
Pastures into Artificial areas	ha	1000	174	170
	%	74.40	12.95	12.65
	transition index	1.46	0.64	0.44

Table 27

Transition indexes and shares of soil water retention capacity classes in various land use conversion types in cluster 3

Conversion type		Low retention (<190 mm)	Medium retention (190-230 mm)	High retention (>230 mm)
Arable land into Forest and semi natural areas	ha	23711	53905	4302
	%	28.94	65.80	5.25
	transition index	0.88	1.16	0.52
Pastures into Forest and semi natural areas	ha	830	2299	231
	%	24.70	68.42	6.88
	transition index	0.95	1.52	0.24
Arable land into Artificial areas	ha	21967	36622	4526
	%	34.80	58.02	7.17
	transition index	1.05	1.02	0.71
Pastures into Artificial areas	ha	1563	3235	901
	%	27.43	56.76	15.81
	transition index	1.06	1.26	0.54

mainly consumes medium retention soils. Although the forestation of medium retention pasture soils is preferential – transition index 1.52. The consumption of arable land to meet demand of urban development also mainly affects soils of medium retention capacity (58.02% of flow), however, the transition index equals 1.02, suggesting that the loss of this retention class is proportional. In general, the retention function of soils in this cluster seems to be well protected.

Within the economically strong and balanced cluster 4, there is a preferential con-

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version of low retention arable soils into forests, which is a positive trend from the sustainability perspective – the contribution of low retention soils in afforestation is also the highest (54.16%). There is also a preferential flow of low retention soils into artificial areas, as reflected by the transition index (1.38), which is indicative of a proper management of some of the land resources. However, high retention soils seem not to be particularly protected against the expansion of artificial surfaces, as shown by transition indexes approaching 1 (Table 28).

Within the urban and non-agricultural cluster 5, soils of medium retention on arable land are intensely converted into artificial areas – shown by a transition index of 2.28. As much as 64.78% of all arable land converted into artificial surfaces represents medium retention capacity. There is also preferential conversion of low retention pasture soils into artificial areas, as reflected by a transition index of 1.86 – this is interpreted as a positive development from a water storage perspective, although on the other hand, building on pasture land is not a sustainable practice. However, the largest amount of pasture consumed by urbanization belongs to medium retention capacity soils (3410 ha). Large acreages of medium retention soils (2478 ha) on a pasture land were converted into forests and semi natural areas – 66.42% of this flow took place on medium retention capacity soils with a transition index 0.89 (Table 29). A preferential conversion of pastures to a forest is observed on high retention soils and the respective transition index is as high as 1.9.

3.5.3. Erosion risk and land use change

Table 28

Transition indexes and shares of soil water retention capacity classes in various land use conversion types in cluster 4

Conversion type		Low retention (<190 mm)	Medium retention (190-230 mm)	High retention (>230 mm)
Arable land into Forest and semi natural areas	ha	18980	12475	3590
	%	54.16	35.60	10.24
	transition index	1.65	0.88	0.38
Pastures into Forest and semi natural areas	ha	7288	14422	4802
	%	27.49	54.40	18.11
	transition index	0.92	1.01	1.11
Arable land into Artificial areas	ha	99968	117844	70989
	%	34.61	40.80	24.58
	transition index	1.06	1.01	0.92
Pastures into Artificial areas	ha	44685	49490	13902
	%	41.35	45.79	12.86
	transition index	1.38	0.85	0.79

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Table 29

Transition indexes and shares of soil water retention capacity classes in various land use conversion types in cluster 5

Conversion type		**Low retention (<190 mm)**	**Medium retention (190-230 mm)**	**High retention (>230 mm)**
Arable land into Forest and semi natural areas	ha	59	288	162
	%	11.59	56.58	31.83
	transition index	0.21	1.99	209
Pastures into Forest and semi natural areas	ha	440	2478	813
	%	11.79	66.42	21.79
	transition index	0.87	0.89	1.90
Arable land into Artificial areas	ha	1836	5902	1373
	%	20.15	64.78	15.07
	transition index	0.36	2.28	0.99
Pastures into Artificial areas	ha	1286	3410	389
	%	25.29	67.06	7.65
	transition index	1.86	0.89	0.67

Erosion can lead to a loss of the soil's biological functions, which triggers feedback mechanisms intensifying change into non-agricultural uses or land abandonment (Verburg, 2006). Some of those eroded soils or soils at risk are converted into built-up areas, leading to sealing, which in turn reduces on-site soil loss, but it also decreases water retention within the landscape and increases the amount of runoff waters, thus accelerating soil erosion down-slope (Fitzjohn et al., 1998; Van Oost et al., 2000; Lin Yu-Pin et al., 2007). Sealing erodible land may also affect surface water quality – there is a direct relationship between the share of impervious area in the watershed, and contamination (Klein, 1979; Sloane Richey et al., 1981; May et. al., 1997; Paul & Meyer, 2001; Sutherland & Tolosa; 2001; Turer et al., 2001).

These off-site effects caused by building-up of erodible land are very complex and site-specific, and are not yet fully studied in terms of a quantitative assessment. In this study, it is assumed that converting highly erodible land into artificial surfaces is rather detrimental. It is more beneficial to manage such land by agriculture, or transform it into a forest or semi- natural areas, or green areas in the urbanization process, assuming that there is a sufficient supply of land less severely exposed to erosion available for building. An intense conversion of highly erodible land into artificial surfaces, reflected by high transition index values, is interpreted as a negative process. Spatial distribution of potential erosion risk grouped into four classes is shown on the map (Figure 16).

Within the industrial, economically and socially weak cluster 1, a majority of all arable and pasture land conversions, either into forests or artificial areas, displayed very low risks of water erosion (<1 t · ha^{-1} · $year^{-1}$). Transition indexes within this erosion category were either slightly above or below 1, which is indicative of non-preferential flows. The transition index characterizing the intensity of conversion

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between arable land and artificial areas is high (2.93) – also the size of this change is remarkable (1796 ha), although in relative numbers it is 6.75% of the total flow of arable land into urbanized areas. There is also a preferential flow between arable land and artificial surfaces observed on lands exposed to a medium erosion risk – shown by a transition index of 3.12. A high value of the transition index (9.35) is also noticed for the flow between pastures and artificial areas on strongly eroded land, although it concerns very small acreage (150 ha). In general, the management of land within cluster 1 in relation to erosion risk is proper, although there is noticeable pressure of urbanization on agricultural land facing medium or high exposure to erosion.

Most of the changes in the rural, economically and socially weak cluster 2 occurred in areas of very low erosion risk (< 1 t · ha^{-1} · year^{-1}). It is noticeable that forestation is more intense on highly erodible arable and pasture land, as indicated by high transition indexes (4.1 and 5.07, respectively), although the absolute acreage of these flows is small (1019 ha for arable land and 194 ha for pastures). Similarly, there is also a preferential conversion of highly erodible arable land into artificial areas (transition

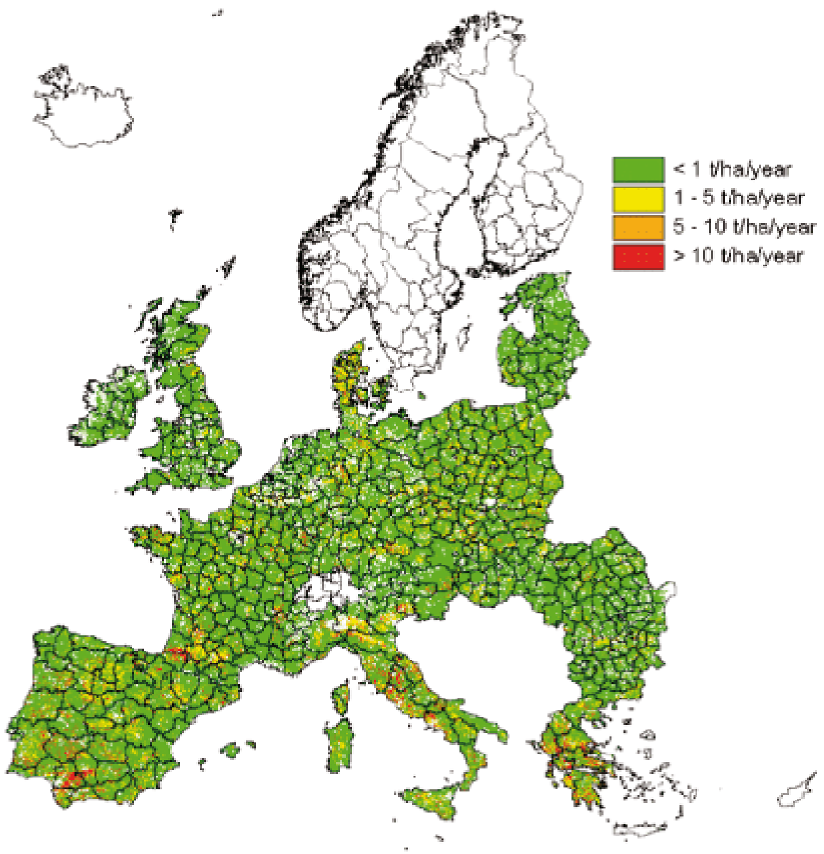

Figure 16. Distribution of soil erosion risk in the EU-25, based on PESERA (Kirkby et al., 2004)

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Table 30

Transition indexes and shares of soil erosion risk classes in various land use conversion types in cluster 1

Conversion type		Very low (<1)	Low (1-5)	Medium (5-10)	High (>10)
Arable land into Forest and semi natural areas	ha	20545	3878	818	281
	%	80.50	15.19	3.21	1.10
	transition index	1.08	0.79	0.80	0.48
Pastures into Forest and semi natural areas	ha	12616	667	188	18
	%	93.53	4.94	1.39	0.13
	transition index	0.97	1.53	3.03	0.53
Arable land into Artificial areas	ha	14402	7092	3337	1796
	%	54.09	26.63	12.53	6.75
	transition index	0.73	1.38	3.12	2.93
Pastures into Artificial areas	ha	5754	392	89	150
	%	90.12	6.14	1.39	2.35
	transition index	0.94	1.90	3.03	9.35

Table 31

Transition indexes and shares of soil erosion risk classes in various land use conversion types in cluster 2

Conversion type		Very low (<1)	Low (1-5)	Medium (5-10)	High (>10)
Arable land into Forest and semi natural areas	ha	8395	1954	572	1019
	%	70.31	16.37	4.79	8.53
	transition index	0.98	0.71	1.49	4.10
Pastures into Forest and semi natural areas	ha	10953	414	71	194
	%	94.16	3.56	0.61	1.67
	transition index	1.07	0.34	0.70	5.07
Arable land into Artificial areas	ha	7165	3597	380	648
	%	60.77	30.51	3.22	5.50
	transition index	0.85	1.33	1.00	2.64
Pastures into Artificial areas	ha	682	179	0	3
	%	78.94	20.72	0.00	0.35
	transition index	0.90	1.95	0.00	1.06

index 2.64), but it accounts for only 5.5% of this flow. A positive aspect of land use change within this cluster is the preferential forestation of highly erodible land.

The economically and socially weak southern cluster 3 has much greater exposure to erosion due to intense relief, soil susceptibility and climate characteristics. Preferential forestation is observed on highly erodible land – 27.56% of all arable land converted into forests belongs to this class, and the transition index is high (2.0). Pastures exposed to high erosion were also preferentially converted into forests (transition index 2.75), although the area size of this change is small (170 ha). Development on arable land

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Table 32

Transition indexes and shares of soil erosion risk classes in various land use conversion types in cluster 3

Conversion type		Very low (<1)	Low (1-5)	Medium (5-10)	High (>10)
Arable land into Forest and semi natural areas	ha	40679	13193	4544	22223
	%	50.45	16.36	5.63	27.56
	transition index	0.95	0.66	0.68	2.00
Pastures into Forest and semi natural areas	ha	2472	509	176	170
	%	74.30	15.30	5.29	5.11
	transition index	0.81	3.32	2.91	2.75
Arable land into Artificial areas	ha	26339	17166	4847	6033
	%	48.43	31.56	8.91	11.09
	transition index	0.91	1.28	1.08	0.81
Pastures into Artificial areas	ha	3904	521	237	142
	%	81.27	10.85	4.93	2.96
	transition index	0.89	2.35	2.71	1.59

Table 33

Transition indexes and shares of soil erosion risk classes in various land use conversion types in cluster 4

Conversion type		Very low (<1)	Low (1-5)	Medium (5-10)	High (>10)
Arable land into Forest and semi natural areas	ha	24632	5429	1621	949
	%	75.49	16.64	4.97	2.91
	transition index	1.14	0.70	0.91	0.61
Pastures into Forest and semi natural areas	ha	23301	782	38	150
	%	96.00	3.22	0.16	0.62
	transition index	1.02	0.81	0.19	0.81
Arable land into Artificial areas	ha	159368	58311	11793	9962
	%	66.56	24.35	4.93	4.16
	transition index	1.01	1.03	0.90	0.87
Pastures into Artificial areas	ha	81418	2854	417	463
	%	95.61	3.35	0.49	0.54
	transition index	1.01	0.84	0.59	0.71

consumes soils of medium and high erosion risk following structural pattern of erosion – transition indexes range around 1, which indicates that there are no particular efforts to minimize the expansion on areas at risk.

The management of erodible land within the western, economically strong cluster 4 is sustainable as between over 90, and 98% of arable and pasture land converted into artificial areas belongs to very low or low erosion risk class (Table 33). Transition indexes within these risk classes mostly range around 1. A very limited number of

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arable and pasture areas on medium or highly erodible land are converted into forests. Transition indexes characterizing these flows are 0.16 and 0.62, respectively. This demonstrates that there has not been a particular policy in place to preferentially change the function of arable steep land into more sustainable forest and semi-natural habitats.

Most of the changes which took place within the economically and socially strong urban and non-agricultural cluster 5 consumed land of very low or low erosion risk (Table 34). Transition indexes for most of the changes occurring within these erosion classes are distributed around 1. Only arable land conversion into a forest on very low erosion risk soils is preferential – transition index 1.68. There are small areas (below 5%) of medium and high erosion risk on arable and pasture land converted into forests.

3.5.4. Soil organic matter and land use changes

The protection of soils rich in organic matter is crucial for maintaining soil functions (Hudson, 1994; Lal et al., 1997; Conant et al., 2004; Dumanski, 2004). Soil organic matter is a property controlling many soil functions, including retention and ecological ones. The loss of organic matter through intense management and oxidation leads to

Table 34

Transition indexes and shares of soil erosion risk classes in various land use conversion types in cluster 5

Concersion type		**Very low (<1)**	**Low (1-5)**	**Medium (5-10)**	**High (>10)**
Arable land into Forest and semi natural areas	ha	376	51	0	0
	%	88.06	11.94	0.00	0.00
	transition index	1.68	0.42	0.00	0.00
Pastures into Forest and semi natural areas	ha	3530	8	0	20
	%	99.21	0.22	0.00	0.56
	transition index	1.04	0.07	0.00	0.64
Arable land into Artificial areas	ha	4,41	1461	315	290
	%	68.73	22.11	4.77	4.39
	transition index	1.31	0.77	0.69	0.37
Pastures into Artificial areas	ha	3875	90	21	39
	%	96.27	2.24	0.52	0.97
	transition index	1.01	0.73	0.74	1.10

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erosion, lowering buffering capacity, retention capacity, and biological activity. Another detrimental impact of organic matter decline is a release of CO_2 to the atmosphere. The conversion of arable land into forests contributes to an increase of OM, and high transition indexes for low OM soils transformed into forests are interpreted as a positive flow. In contrast, the interpretation of high values of transition index (over 1.3) for high OM soils, converted into artificial surfaces is negative, whereas a transition index below 0.7 is assumed to be indicative of an efficient protection of OM rich soils.

Spatial distribution of OM in European soils is presented on the map (Figure 17).

In cluster 1, most of the arable land converted into forests belongs to high and very high OM soils (22.76 and 39.76%, respectively). Respective transition indexes are 0.92 and 0.96. The majority of the forested pasture lands were also very high OM soils (60.73%). It is remarkable that the lower OM content soils represent a lower share in flows between agricultural land and forest. As regards arable land conversion into artificial areas, almost 30% of this change took place on very high OM soils. In

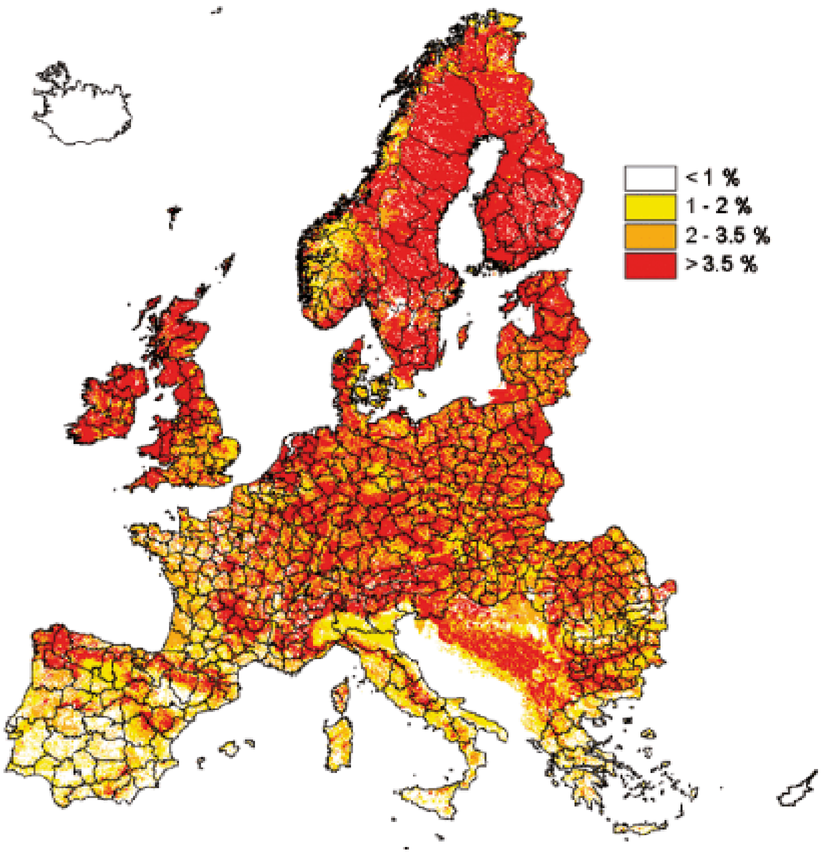

Figure 17. Spatial distribution of soil organic matter in Europe % of carbon (Jones et al., 2005)

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addition high OM soils have a significant contribution to this change (21.55%). The largest share of arable land converted into urbanized areas represents medium OM soils (41.79%). Considerable acreage of high and very high OM soils on pasture land are converted into artificial surfaces (2589 ha and 2932 ha, respectively), which accounts for more than 70% of this flow. Very high OM pasture soils were preferentially converted into artificial surfaces – transition index 1.67. The highest intensity of conversion is noticed for low OM soils, which were transformed into built-up areas on arable (1.84) and pasture land (2.82). Preferential transition also concerns high OM pasture soils changed into artificial areas (transition index 1.67). In general, the protection of OM resources is achieved in cluster 1, with the exception of OM rich soils on pasture land, which are preferentially urbanized.

In the rural cluster 2, there is a considerable contribution of very high OM soils in forestation (6047 ha), which accounts for more than 50% of forest expansion. Pasture land afforested mainly represents very high OM soils (85.77%) – the acreage of very high OM soils forested (10285 ha) was even larger than that of arable land. Although both on arable and pasture land, these flows reflect OM structural pattern within soil cover of the agricultural land (transition indexes 1.13 and 1.06, respectively). The share of low OM soils in forestation is 11.43% only, but this transition is strongly preferential, as shown by the transition index of 3.2.

The majority of artificial surface expansions that occured on arable land consumed very high OM soils – 7342 ha, which is 51.19% of this flow. This, however, corresponds to the share of very high OM soils in the soil cover – transition index 1.15. About one-fifth of artificial areas expansion on arable land took place on high and medium OM soils – Table 36. Built-up areas on arable land poor in OM, consumed 829 ha (5.78%) only, but the transition index of 1.62 demonstrates that this is a prefer-

Table 35

Transition indexes and shares of soil OM classes in various land use conversion types in cluster 1

Conversion type		**Low OM (<1% C)**	**Medium OM (1-2% C)**	**High OM (2-3.5% C)**	**Very high OM (>3.5% C)**
Arable land into Forest and semi natural areas	ha	1113	8771	6001	10483
	%	4.22	33.26	22.76	39.76
	transition index	0.70	0.96	0.89	1.18
Pastures into Forest and semi natural areas	ha	294	2167	2993	8435
	%	2.12	15.60	21.55	60.73
	transition index	0.60	1.21	1.06	0.96
Arable land into Artificial areas	ha	3417	12906	6655	7905
	%	11.06	41.79	21.55	25.60
	transition index	1.84	1.20	0.84	0.76
Pastures into Artificial areas	ha	755	1306	2589	2932
	%	9.96	17.23	34.15	38.67
	transition index	2.82	1.34	1.67	0.61

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ential flow. There is a preferential conversion of low OM pasture soils into artificial surfaces (transition index 7.27), although the acreage consumed is very small (135 ha) – the same concerns an intense transition of high OM soils into built-up areas. The protection of organic matter resources in relation to land use changes seems to be insufficient in this cluster, and no conservation effort has been undertaken yet.

Southern cluster 3 is particularly susceptible to OM loss through erosion, and therefore protecting OM-rich soil is fundamental for maintaining soil functions here. In fact, preferential forestation can be observed on high and very high OM soils, which is reflected in relatively high transition indexes – 1.83 and 1.49, respectively (Table 37), although the relative contribution of these OM classes to forestation taken together is 20% only. Acreage-wise, low OM arable land soils were dominantly forested (44408 ha, 54.17%), although a transition index of 1.02 provides evidence that it reflects general distribution of OM in arable soils. Low OM pasture soils were preferentially forested – transition index 2.16. Expansion of urbanization and infrastructure mainly took place on low OM soils (43348 ha), which accounts for 68.44% of the entire arable land converted – there is also some, but not very strong, indication of preferential use of low OM soils for urbanization, reflected by a transition index 1.29. Transition indexes for higher OM classes on pastures are between 0.69 and 0.61, which indicates a tendency for an adequate protection of these soils against urbanization. In general, conversion of arable and pasture land into artificial surfaces tends to protect high OM soils.

In the economically and socially strong western cluster 4, very high organic matter soils account for 63.23% of arable land converted into forests (Table 38), and this is evidently a preferential change relative to distribution of OM in arable soils – transition index 1.97. It is interesting that low OM soils were avoided in forestation process

Table 36

Transition indexes and shares of soil OM classes in various land use conversion types in cluster 2

Conversion type		Low OM (<1% C)	Medium OM (1-2% C)	High OM (2-3.5% C)	Very high OM (>3.5% C)
Arable land into Forest and semi natural areas	ha	1377	1942	2685	6047
	%	11.43	16.11	22.28	50.18
	transition index	3.20	0.65	0.82	1.13
Pastures into Forest and semi natural areas	ha	95	713	898	10285
	%	0.79	5.95	7.49	85.77
	transition index	0.57	0.85	0.71	1.06
Arable land into Artificial areas	ha	829	3372	2800	7342
	%	5.78	23.51	19.52	51.19
	transition index	1.62	0.94	0.72	1.15
Pastures into Artificial areas	ha	135	12	238	959
	%	10.04	0.89	17.71	71.35
	transition index	7.27	0.13	1.68	0.88

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Table 37

Transition indexes and shares of soil OM classes in various land use conversion types in cluster 3

Conversion type		Low OM (<1% C)	Medium OM (1-2% C)	High OM (2-3.5% C)	Very high OM (>3.5% C)
Arable land into Forest and semi natural areas	ha	44408	20861	15433	1273
	%	54.17	25.45	18.83	1.55
	transition index	1.02	0.71	1.83	1.49
Pastures into Forest and semi natural areas	ha	1010	805	1163	382
	%	30.06	23.96	34.61	11.37
	transition index	2.16	0.62	1.09	0.72
Arable land into Artificial areas	ha	43348	15589	4000	404
	%	68.44	24.61	6.32	0.64
	transition index	1.29	0.69	0.61	0.61
Pastures into Artificial areas	ha	1090	2429	1748	478
	%	18.97	42.28	30.43	8.32
	transition index	1.37	1.10	0.96	0.52

– transition index 0.41. On pasture land 77.29% of forested area represented low OM soils (Table 38), although it was almost proportional to their share in the soil cover – transition index 1.23 (Table 38). It is rather negative that low and medium OM arable land soils are underrepresented in forestation – less than half as much of these soils are forested as compared to their contribution to arable land – transition indexes about 0.4 (Table 38). Very high OM pasture soils contribute to 77.29% of pasture land forested – the acreage (20516 ha) is almost as large as for arable land in this OM class, although this change is almost proportional – transition index 1.23. Forestation of high OM soils is positive from the perspective of ecosystem functioning and biodiversity, as it contributes to the conservation of large OM pools, which can further increase under forest and semi-natural habitats (Rőmkens et al., 1999). The conversion of arable land into artificial areas was nearly equally distributed between very high, high and medium OM soils (35.67%, 28.61% and 28.44%, respectively). The transition indexes for these OM classes indicate that their conversion into artificial surfaces is not preferential, as they range between 0.83 and 1.23. Low OM soils are underrepresented in the expansion of urbanization of arable land – transition index 0.69. Development on pasture land consumes mainly very high and high OM soils (66.63% and 20.23%, respectively) – this change follows the pattern of OM distribution in arable soils – transition indexes 0.91 and 1.06 (Table 38). A significant contribution of OM rich soils to urbanization is definitely a negative aspect of land use change in cluster 4.

In the urban and non-agricultural cluster 5, there is a remarkable area of pastures (3448 ha) converted into forests on very high OM soils, which constitutes 92.32% of the whole pasture land forestation – very probably, these are wet habitats, on which agricultural use is no longer practical in an urban environment. This change is

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Table 38

Transition indexes and shares of soil OM classes in various land use conversion types in cluster 4

Conversion type		**Low OM (<1% C)**	**Medium OM (1-2% C)**	**High OM (2-3.5% C)**	**Very high OM (>3.5% C)**
Arable land into Forest and semi natural areas	ha	1521	5098	6313	22239
	%	4.32	14.49	17.95	63.23
	transition index	0.41	0.43	0.77	1.97
Pastures into Forest and semi natural areas	ha	1131	1598	3300	20516
	%	4.26	6.02	12.43	77.29
	transition index	1.17	0.54	0.56	1.23
Arable land into Artificial areas	ha	21038	82246	82746	103165
	%	7.27	28.44	28.61	35.67
	transition index	0.69	0.83	1.23	1.11
Pastures into Artificial areas	ha	5011	9245	21943	72285
	%	4.62	8.52	20.23	66.63
	transition index	1.26	0.77	0.91	1.06

Table 39

Transition indexes and shares of soil OM classes in various land use conversion types in cluster 5

Conversion type		**Low OM (<1% C)**	**Medium OM (1-2% C)**	**High OM (2-3.5% C)**	**Very high OM (>3.5% C)**
Arable land into Forest and semi natural areas	ha	80	51	126	252
	%	15.72	10.02	24.75	49.51
	transition index	2.84	0.36	0.76	1.46
Pastures into Forest and semi natural areas	ha	35	125	127	3448
	%	0.94	3.35	3.40	92.32
	transition index	0.37	0.63	0.23	1.19
Arable land into Artificial areas	ha	416	2978	3810	1921
	%	4.56	32.64	41.75	21.05
	transition index	0.82	1.16	1.29	0.62
Pastures into Artificial areas	ha	135	429	1326	3195
	%	2.65	8.44	26.08	62.83
	transition index	1.04	1.58	1.80	0.81

proportional to the share of very high OM pasture soils in soil cover – transition index 1.19. Very limited areas of arable land are converted into forests – from 51 ha for medium OM soils to 252 for very high OM soils. As regards high and very high OM soils, within arable land afforested, 49.51% represents very high OM soils and this flow is preferential. Concerning urbanization of arable land – the largest areas consumed represent high OM soils (3810 ha), comprising 41.75% of this flow, which is slightly preferential (transition index 1.29). In terms of OM protection objectives – very high

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OM soils are less intensely consumed by urbanization (transition index 0.62), whereas high OM soils tend to be overrepresented in this flow (transition index 1.29).

3.5.5. Summary assessment of land use change in the context of soil protection in Europe

Evaluating the preferential flows of arable and pasture land into artificial surfaces for each of the soil function aspects makes it difficult to arrive at a general assessment of the impact of development on soil resources and their functions. Similarly, the above analysis does not give a synthetic view on how, where, and to what extent the expansion of forests serves the improvement of soil conservation. Combining the results of analysis of how development relates to soil quality parameters can give a general view on soil protection trends. It is proposed to consider that a development leading to a removal of the best soil resources is defined as unsustainable. In order to recognize the regions where this process is most severe, the following threshold criteria were used: over 30% of built-up areas took the place of an agricultural land meeting one or more of the following characteristics - very high OM content, high water retention capacity, high land suitability, very high exposure to erosion risk. Another condition assumed for this assessment is that areas meeting any of the above characteristics are preferentially converted into artificial surfaces (transition index >1.3), meaning that their share in newly built-up areas is at least by 30% larger than their proportion in the soil cover of the total agricultural land in a given NUTS-x unit. It is assumed that a preferential conversion of high quality and high retention capacity soils, as well as of land which is severely exposed to erosion, creates a risk for impeding important functions of landscapes in the expanding urban environment. These assumptions respect a well established fact that the conversion of agricultural land into urban areas usually comes with a vast increase of impervious surfaces, which can alter the natural hydrologic condition within the watershed (Tang et al., 2005). It is well understood that the outcome of this alteration is typically reflected by increases in the volume and rate of surface runoff, and decreases in ground water recharge and base flow (Moscrip and Montgomery, 1997), which eventually lead to larger and more frequent incidents of local flooding (Field et al., 1982). Other impacts of urbanization include a modified watershed water balance (Fohrer et al., 2001), and an increased erosion of river channel beds and banks (Doyle et al., 2000).

A general assessment of an arable and pasture land transition pattern into artificial surfaces, in relation to some of the aspects of soil and land quality is presented in Figure 18.

The largest arable land areas of potentially unsustainably managed soils, preferentially converted into artificial surfaces, resulting in a risk of impeding soil functions, are OM rich soils (Figure 18). They are distributed mainly in the UK, France, Finland, Sweden, the Baltic States, Poland and Slovakia. In the case of Poland, the OM con-

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tent in soils, as derived by Jones et al. (2005), seems to be overestimated – the data presented by Terelak et al. (1997) based on 50000 measurements of soil carbon in top horizons indicates that more than 60% of soils are of low OM content. Therefore the stock of negative flows, affecting soil functions may be biased at least to some extent.

There are a few regions in Austria and France where a preferential expansion of built-up areas on OM rich soils coincides in the same NUTS unit with a conversion on highly suitable land (OM+LS, Figure 18). The second largest stock of non-sustainably converted arable land into artificial surfaces, which does not coincide with any other considered parameter in one NUTS unit, concerns highly erodible land, followed by high water retention soils (Figure 18). Erosion is a problem in built-up areas in the south, mainly in Italy, France, Spain, and Greece. It is also notable in Slovakia. High water retention soils, which are preferentially converted into built-up areas, are scattered throughout Europe with more abundance in eastern regions. In addition to this, there are regions where preferential conversion meets a larger number of criteria assumed for the assessment of non-sustainable flows into urban land - regions where a number of non-sustainable transitions coexist, but not necessarily spatially overlap are shown on the map (Figure 18).

Summing up all non-sustainable flows into built-up areas, the total acreage of valuable soils that were not efficiently protected against sealing on arable land is 36893 ha (Table 40).

Similarly to arable land, a preferential non-sustainable expansion of artificial areas on pastures mainly concerns OM rich soils, predominantly in France, the UK, Spain,

Arable land flows into artificial surfaces

Pasture land flows into artificial surfaces

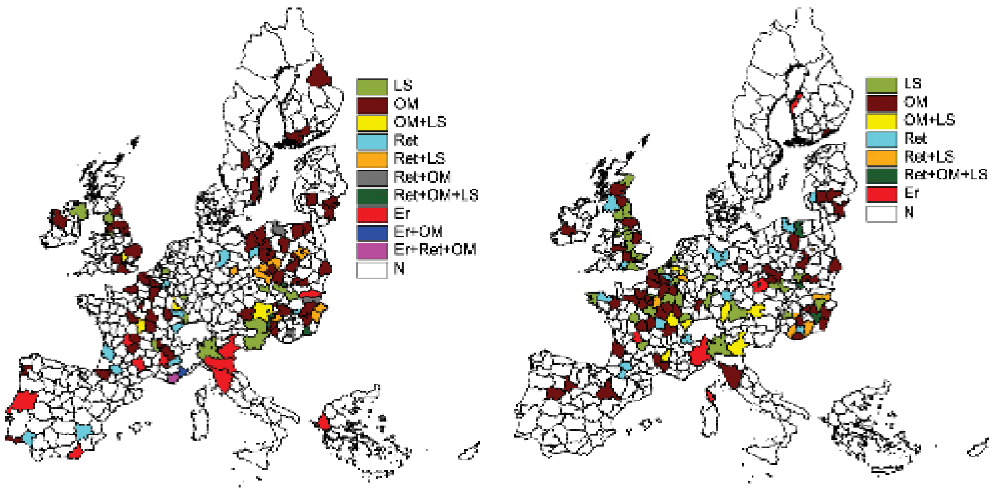

Figure 18. Spatial distribution of regions where agricultural land conversion into artificial surfaces strongly affects soil functions. Abbreviations used: Ls – high land suitability, OM – high OM soils, Ret – high water retention capacity soils, Er – highly erodible soils, N- neutral regions outside boundaries of assessment criteria

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Hungary, Poland and the Baltic States (Figure 18). Regions facing a preferential conversion of high suitability pasture land are mainly in the UK. There are a number of regions, which are scattered throughout Europe, where conversion has consumed high water retention soils. This often coincides with high land suitability and high OM content (Figure 18).

In contrast to the unsustainable growth of artificial areas, positive trends have also been identified - associated with the forestation and expansion of semi-natural areas on low quality land, OM low soils, and low water retention capacity soils, as well as areas that are highly exposed to erosion. It is assumed that changing the habitat of such areas improves soil functions, leads to the accumulation of OM, increases water retention, and reduces erosion risk. It is well established that the higher interception of precipitation by forest reduces floods by removing a portion of rainfall and by allowing a build-up of soil moisture storage. This effect is generally small, but significant for small storms. High infiltration rates under forests and an effective soil cover reduce surface runoff and erosion (Calder, 1992). Increasing the level of soil organic carbon and organic matter can provide considerable environmental and agricultural benefits (Dumanski, 2004). Increased soil organic matter normally improves soil aggregation, which in turn improves soil aeration, reduces soil erosion, improves infiltration, and generally protects surface and groundwater quality. In addition, increased soil organic matter enhances soil water storage capacity (Hudson, 1994). Increasing the soil's organic matter through carbon sequestration also controls nutrient cycling by stimulating soil biology and bio-diversity. The amount and quality of soil organic matter is an important indicator of soil quality and health (Lal et al., 1997; Dumanski, 2004), and this is directly influenced by land management practices. The transition from arable land to non-agricultural functions is expected to affect both the quantity and quality of soil organic matter within a few decades, which changes both the nutrient status, as well as the soil's capacity to retain water and contaminants (Römkens et al., 1999). Coarse textures are the most vulnerable to mineralization, following a conversion of forests to arable land – therefore it is logical to expect significant gains following the conversion back into a forest. Although conversion into forests may not necessarily and automatically lead to an OM increase, particularly in the case of a pasture – the

Table 40

Summary of acreage size and ratios between positive and negative agricultural land flows in 5 European Clusters

Cluster	Positive [ha]	Negative [ha]	Difference [ha]	Ratio Pos./Neg.	GDP [€]
1	8363	4276	4087	2.0	8987
2	8949	4130	4819	2.2	4504
3	9360	366	8994	25.6	15680
4	12829	26951	-14122	0.5	24010
5	816	1170	-354	0.7	27303
EU25	40317	36893	3424	1.1	18627

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management following the conversion is likely to be an important factor controlling whether conversion leads to net carbon (C) loss, net C sequestration, or no change (Fearnside & Barbosa, 1998)

Considering the above body of arguments, similar threshold criteria, as those for non-sustainable flows of agricultural soils into artificial surfaces, were used to delineate areas where land use change into forests and semi-natural areas should improve soil functions. The conditions were as follows: at least 30% of the transition of arable or pasture land conversion into forests is on land meeting one or more of the following characteristics – low OM content, low land suitability, low water retention capacity, very high exposure to erosion risk. It is also required that the respective transition indexes must be >1.3.

The output of the analysis based on the above criteria shows that considerable areas of pastures on erodible land were preferentially forested in Spain, Italy, and France (Figure 19).

It is advantageous that arable land conversion into forests and semi-natural areas preferentially consumes low water retention soils and this often coincides with low OM soils localized in the same region. The spatial pattern of such soils correlates quite well with glacial till plains of Northern Europe. These soils are of limited suitability for agriculture and converting them into forests creates a potential for carbon sequestration, for an improvement of water retention within landscapes, and improving biodiversity. Forestation of low quality and permeable land is likely to have a positive impact on the reduction of nutrients leaching into surface and ground waters (Tong & Chen, 2002).

A preferential conversion of pastures into forests and semi-natural areas mainly took place on low retention soils, particularly in Poland, but also in some regions in Germany, France, and the UK. A preferential forestation and conversion into semi-natural areas concerns soils of low OM and high erosion coinciding in one region – a few such units are identified in Spain. Low land suitability pastures are preferentially forested in Southern Europe, and also in Slovakia and the UK (Figure 19). Total areas of arable and pasture land preferentially converted into forests and semi-natural areas, leading to a more sustainable use of soils, and a better protection of their functions came up to 27780 ha and 12534 ha, respectively (Table 41).

Data in Table 41 demonstrates the acreage of positive and negative flows and their share in the total conversions in clusters, including the numbers for arable and pasture land. It is remarkable that forestation of poor quality pasture soils accounts for 44% of all soil pasture flows into forests. Since pastures are mainly located in valleys, these shifts can be indicative of a recovery of riparian zones playing an important role in the improvement of buffering capacity by stripping nitrogen leaching from agricultural fields through increased denitrification (Angier et al., 2001), as well as by contributing to habitat diversity and biotic integrity of streams (Miltner et al., 2004; Moffat & McLachlan, 2005), and a decline of local flooding incidents (Tang et al., 2005).

A summary comparison between the acreage size of positive and negative conversions of agricultural land into other functions, shown for the five European clusters

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Arable land flows into a forest   Pasure land flows into a forest

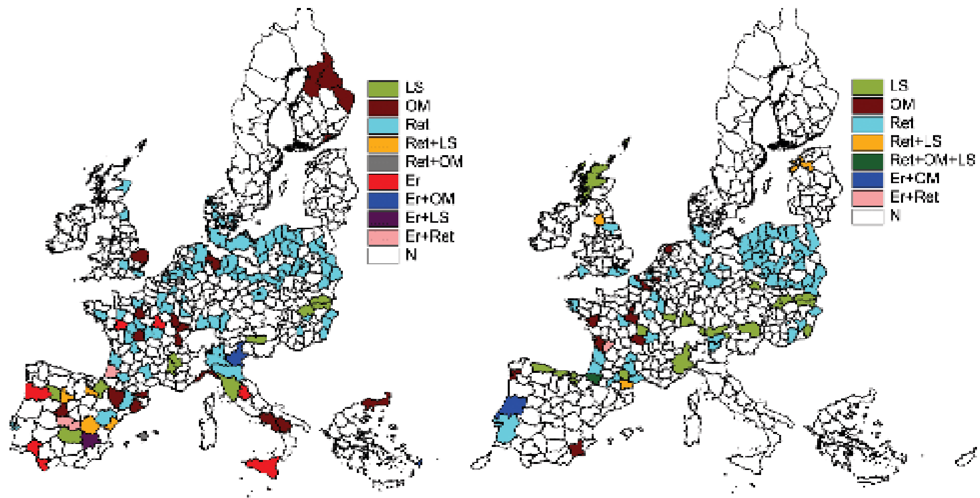

Figure 19. Spatial distribution of regions where agricultural land conversion into forests and semi-natural areas improves soil functions. Abbreviations used: LS – low land suitability, OM – low OM soils, Ret – low water retention capacity soils, Er – highly erodible soils, N- neutral regions outside boundaries of assessment criteria

and in the EU-25, is based on numbers derived by summing all areas of sustainable flows (positive) of agricultural land into forests and semi-natural areas, as well as unsustainable transitions into artificial areas, affecting important soil functions (negative) – Table 41.

The ratio between positive and negative flows can be considered as a land resource impact indicator (LRI) for soils, reflecting to what extent unsustainable management leading to a loss of soil functions is compensated elsewhere by an efficient conservation and improvement of soil functions. Another LRI can be a percentage of negative flows affecting soil quality in relation to the total area transformed into artificial surfaces – positive shifts prompting soil conservation can be assessed in a similar way (Table 41). The concept of LRI is widely discussed by Hasse and Lathrop (2003), and it includes an indicator of prime farmland loss in the urban development process, but there are no other soil quality related LRIs proposed yet.

Ratios between positive and negative flows clearly show that in the economically and socially weak clusters (1, 2 and 3), sustainable changes prevail. In clusters 1 and 2, the acreage of positive changes is twice as large as that for negative changes, whereas in the southern cluster, the ratio between positive and negative flows is as high as 25.6. Prevailing sustainable conversions in the Southern cluster are probably driven by climate conditions forcing changes in management practices and shifts of agricultural land with low quality soils into forests and semi-natural areas – although flows in either direction concerns a very limited area (Table 40). In general, in cluster

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Table 41

Total acreage and relative share of unsustainable (positive) and sustainable flows (negative) of arable and pasture land, assessed in the context of soil protection objectives in European clusters

Region	Negative (ha)		Positive (ha)		Negative (%)		Positive (%)	
	aa	pa	af	pf	aa	pa	af	pf
Cluster 1	3091	1191	5812	2542	10.0	15.7	22.9	18.3
Cluster 2	3926	204	4283	4672	27.5	15.1	35.5	38.9
Cluster 3	282	84	7728	1632	0.4	1.5	9.5	48.6
Cluster 4	16314	10638	9941	2888	5.6	9.8	28.4	10.9
Cluster 5	896	267	16	800	9.9	5.2	3.1	21.4
EU-25	24509	12384	27780	12534	6.0	9.7	18.0	21.1

Explanation of symbols – **aa:** flows of arable land into artificial surfaces, **af:** arable land into forests, **pa:** pastures into artificial surfaces, **pf:** pastures into forests. Positive flows forestation on low LS low retention soils low OM content highly erodible land. Negative flows – building on high LS, high retention capacity soils, high OM soils, highly erodible land.

3, the dominating flows are interpreted as neutral from a soil conservation standpoint, by the criteria set in this study.

Even though in clusters 4 and 5, the area size of non-sustainable conversions, which are potentially detrimental for soil functions, was twice as large compared to the flows protecting soil habitats, these negative conversions accounted for less than 10% of total flows between arable and artificial surfaces (Table 41). It should therefore not be misinterpreted that in the economically strong clusters 4 and 5, the pressures related to development cause particularly negative flows affecting soil quality. This picture is rather due to a relatively less intense forestation meeting soil protection criteria taken in this study, as indicative of efficient conservation.

It is apparent that in clusters 1 and 2, the negative changes are compensated by positive flows, unlike in clusters 4 and 5 (Table 40). However, when assessing the share of unsustainable flows of arable land into artificial surfaces (aa), it is striking that as much as 27.5% of the expansion in the rural cluster 1 meets the criteria proposed for a non-sustainable use of soils, potentially affecting soil functions either through a conversion of prime quality agricultural land, transformation of high water retention capacity soils, OM rich habitats, highly erodible land, or spaces jointly meeting more than one of these characteristics (Table 41). There is an almost negligible share of unsustainably developed urban areas on arable land in the southern cluster 3, with regards to soil quality thresholds used in this analysis. In other clusters, the expansion of urban fabric on arable land, in a way which strongly affects soil functions and could be indicative of a lack of efficient soil protection policy, does not exceed 10% of the total flow (Table 41). Interestingly, in the western economically strong cluster 4, only 5.6% of arable land flows into urban areas are significantly preferential in locations affecting soil functions, even though half of it only is compensated by environmentally sound conversions (Table 40).

With regard to the expansion of urban fabric on pastures, the flows observed in cluster 1 and cluster 2 are also the least sustainable, since about 15% of all conver-

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sions affect areas where it can lead to a conflict with soil protection objectives. In cluster 3, unsustainable conversion of pastures into built-up areas is almost negligible, relative to total flows (1.5%). In cluster 4 it does not exceed 10%, although acreage-wise, the size of the unsustainable development area is the largest among clusters (10638 ha). It should be emphasized that building on pasture land itself, and in particular in valley flood plains is non-sustainable from a hydrological perspective, and the soil quality aspect is just another dimension of the related risks.

In a conclusion, it seems evident that in the southern EU there is no particular pressure of development that threatens soil functions, neither are there any substantial positive flows towards soil conservation according to the criteria used in this study. In the western EU there are limited positive flows relative to negative development, but the latter has a limited share in the expansion of artificial surfaces. Moreover, the flow of arable land into forests in this region, potentially conserving soil functions, accounts for almost one-third of the entire transition in this direction. The differences in pattern of positive and negative flows between EU clusters, as regards soil conservation aspects, seem to be driven by GDP – in the economically weaker rural and industrial clusters 1 and 2 it is easier to compensate negative flows by forestation, as urbanization is not so extensive and there is less competition for marginal land from other sectors. Whereas in the economically stronger western cluster 4, the compensation of negative flows by positive shifts is lower, as there is probably a more efficient use of marginal land by agriculture. Considering negative flows, regardless of the area size of compensating positive shifts, it is clear that in the new member states the expansion of artificial surfaces on agricultural land during the period 1990–2000 was less sustainable in terms of soil conservation as compared to the former EU-15.

3.6. SILESIA CASE STUDY – ANALYSIS OF LAND USE CHANGE IN THE CONTEXT OF SOIL CONTAMINATION

3.6.1. Regional characteristics

Silesia is an administrative region located in southern Poland on the border with the Czech Ostrava region (Figure 20). It displays very diverse characteristics, from a highly industrialized and polluted central part to a mountainous and more rural character in the south. This region has been under heavy pressure from the mining and smelting industries, the development of which dates back to the Middle Ages. The industry generated a number of post-industrial waste and dump sites, as well as contributed to extensive soil contamination in the central part of the Upper Silesia region. The total area of the region is 12334 km^2 and its population comes to over 4.6 million inhabitants, which makes it the most densely populated region in Poland (GUS, 2006). Large differences also occur in physiogeographic conditions, demography, socio-economic patterns, land quality, farming systems, and contamination levels. A substantial part of soils in the region, particularly in the central part, is contaminated by heavy metals (Dudka et al., 1995). Soil quality may also be affected by organic pollutants

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(Bodzek et al., 1998; Maliszewska-Kordybach & Smreczak, 2002). Due to this diversity, Silesia can not be analyzed as a whole, and sub-regional patterns should be recognized, particularly for the assessment of land use change in the context of soil contamination. Consequently, four relatively homogenous clusters were distinguished based on socio-economic and biophysical variables listed in the methodology section. A summary of the characteristics of each cluster is given in Table 42, while spatial distribution is shown in Figure 20 – variables are grouped into environmental, socio-economic and impact indicators showing soil quality status, potential impact of industry, demographic patterns and structural features of farming systems.

Cluster 1 groups NUTS-5 units (gminas) that are non-industrial and have a significant contribution of forests to their total area (Table 42). This cluster is mainly located in the southern part of the region, which represents a mountainous landscape, and also in areas north of the industrial, polluted cluster 2 (Figure 20). An important feature of

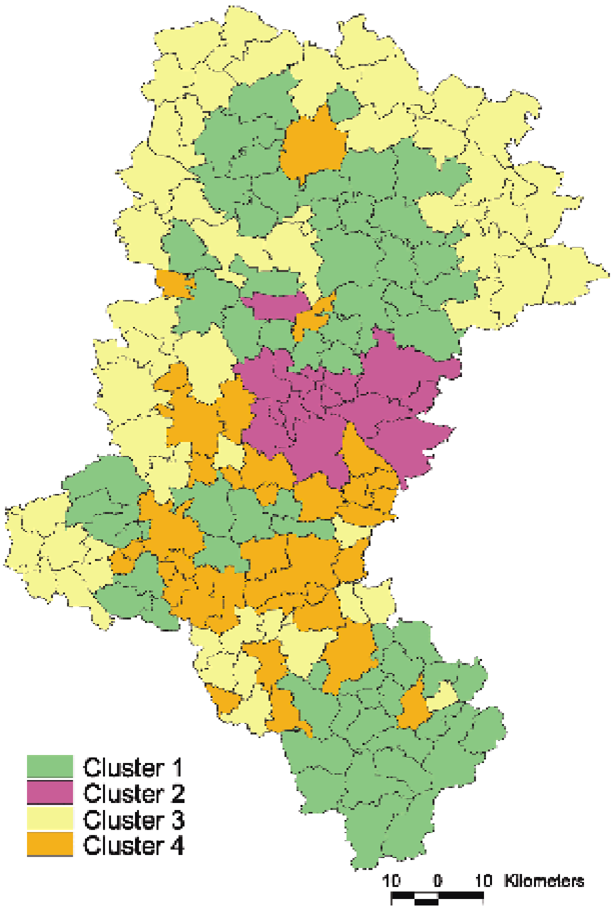

Figure 20. Spatial distribution of NUTS-5 within clusters in the Silesia industrial region of Poland

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cluster 1 is the largest contribution of protected areas (38.68%), as compared to other sub-regions. Pressure of industry on terrestrial ecosystems is relatively marginal as reflected by dust and gaseous emissions.

Cluster 2 consists mainly of industrial and post-industrial areas located in the central part of the region – it faces serious soil contamination, high industrial emissions to the atmosphere and water bodies (Table 42). Population density here is the highest among the four clusters, but there has been a constant trend of population decline observed within the last eight years, due to pollution and the collapse of the smelting industry.

Cluster 3 groups agricultural areas with a large share of agricultural land and with more intense agricultural production, relative to the surrounding clusters (Table 42).

Table 42

Means of selected environmental, impact and socio-economic variables characterising Silesian clusters

Variables	Silesia	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Environmental					
Mean erosion index[1]	1.34	1.57	1.21	1.19	1.23
Mean zinc content in soil[1] ($mg \cdot kg^{-1}$)	185	145	797	85	140
Mean cadmium content in soil[1] ($mg \cdot kg^{-1}$)	1.7	1.4	6.5	0.8	1.3
Mean lead content in soil ($mg \cdot kg^{-1}$)	71	63	260	35	55
Land Quality Index[2]	64.9	56.2	65.4	68.8	69.5
Agricultural land area[3] (% of total)	50.82	44.25	32.11	64.57	49.59
Forest area[3] (% of total)	29.37	42.13	21.91	23.67	19.92
Protected areas[3] (% of total)	22.55	38.68	5.96	no data	7.56
Impact					
Dust emissions[3] ($t \cdot km^{-2}$)	5.6	2.9	12.1	1.5	6.9
Gaseous emissions[3] ($t \cdot km^{-2}$)	53	8.9	148	3.1	75
Industrial waste produced (thousands $t \cdot km^{-2}$)	14.6	4.6	14.3	1.8	24.2
Socio-economic					
Population density[3] ($inhabitants \cdot km^{-2}$)	465	236	1871	140	759
Natural population growth[3] (persons/1000 inhabitants)	-0.79	-0.64	-2.84	-1.24	0.57
Unemployment rate[3] – total (%)	10.0	10.3	12.5	9.8	8.9
Mean farm size[3] (ha)	2.80	2.08	1.69	4.57	1.95
Farms[3] < 5ha (%)	90	96	97	80	94

Values calculated based on: 1 – IUNG data; 2 – Witek & Górski, 1977; 3 – GUS, 2006

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The level of industrial pressure is smaller, as indicated by lower emissions and waste production. Population density is also the lowest, compared to the other clusters, which reduces the potential pressure of development on agricultural land.

Cluster 4 is the most interesting from a structural point of view, and it represents industrial areas that are recovering economically and becoming active again, as indicated by the highest local community budget income per inhabitant (Table 42). It is also the only cluster with a positive value of natural population growth in 2002 (Table 42), which, if it continues, may be countering the population density decline trend. The conversion of agricultural land into artificial surfaces (mainly into construction sites) was the largest compared to the other clusters – detailed data on land flows are discussed further, in the context of soil contamination.

Analyzing land use CORINE data for Silesia shows that changes in 1990–2000 were either negligible or not detected, likely due to the generalization of the change layer (Table 43). There is a contrasting difference in the CORINE change layer between Silesia and the neighbouring Ostrava region in Czech Republic, representing a similar industrial character (Figure 21). It is unlikely that the density of change would be so different in the two adjacent regions of a similar historical and industrial background, and therefore it is justified to assign these discrepancies to methodology in land use classification used by national teams. This is evident by comparing density and distribution of land use changes shown on the CORINE map (Figure 21). For this reason, it was decided to use a higher resolution data characterizing land use changes, although the time frame of this material is not so well defined, as it was derived from a combination of satellite image classification from the late eighties, and topographic and soil maps from earlier periods. A tentative assessment of the time reference of the 30 m resolution change layer is the period 1980–2002.

3.6.2. The distribution of soil contamination in Silesia and potential impacts

Table 43

Assessment of land use change in Silesia depending on data resolution

Type of conversion	30 m resolution 1980–2002			(CORINE) 1990–2000	
	Area of change [ha]	Percent change		Area of change [ha]	Percent change
		Relative to total area	Relative to class area		
Silesia					
Arable land – Forest	40657	1.36	11.24	0	0.000
Pasture – Forest	30540	2.48	20.47	485	0.039
Arable land – Artificial areas	44960	3.65	8.10	870	0.071
Pasture – Artificial areas	1679	3.30	7.32	230	0.019

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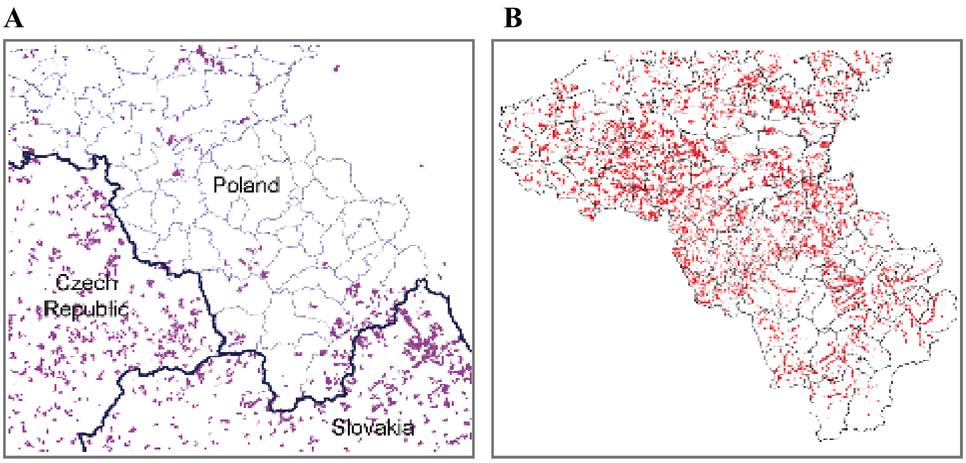

Figure 21. Comparison of detail level between CORINE change layer CLC1990/2000 (A) and 30 m resolution data for Silesia (B)

An analysis of agricultural land loss due to urbanization and expansion of industrial areas is made with reference to soil contamination legal thresholds, indicating the location and scale of associated health and environmental risks. Regulatory values were introduced in Poland in 2002 that set thresholds for metals and organic substances in soils, depending on current or planned land use function (Ministry of the Environment, 2002). Maximum permissible levels were differentiated into three classes - the lowest metal thresholds were set for protected land (class A), higher limits are accepted for agricultural land and urban areas (class B) and most liberal values are defined for communication network and industrial development (class C).

Presumably these thresholds recognize health and environmental risks associated with the exposure to contamination. Legally, class C soils should not be used for residential development, and the risk here is associated with the inhalation of fugitive dust generated by wind erosion, the movement of contaminants into ground water used for drinking purposes, and the contamination of plants grown in backyard gardens. Land use maps utilized in this study do not distinguish between industrial/commercial functions and urban areas within artificial surfaces, although based on the analysis of other high resolution land use data , it is fair to assume that 85% of the flow into artificial surfaces on class C agricultural land was due to an urban function, which means building on contaminated land. It is likely that a major part of this conversion took place over past decades, prior to the implementation of regulatory values in 2002.

From the perspective of environmental impact, it is evident that there is a strong relationship between land-use type, soil contamination level and the quantity and qual-

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ity of water (Gburek and Folmar, 1999). Building on contaminated land involves off-site effects caused by carrying contaminated sediments and dissolved metals into streams affecting biota – the elevated levels of heavy metals can be found in surface waters in areas with a high percentage of impervious cover (Klein, 1979; Sloane Richey et al., 1981; Paul & Meyer, 2001; Sutherland & Tolosa, 2001; Turer et al., 2001). It has been recognized that the most serious source of lead exposure in urban areas today is contaminated dust and soil (Hackley & Katz-Jacobson, 2003), which can lead to detrimental impacts on human health (Ljung et al., 2006). In Silesia, direct emissions from installations have dramatically declined in the last 15 years, due to the collapse of the zinc and lead industry, however, secondary emissions of fugitive dust from barren smelter piles and contaminated soils remain a major problem as they are quite abundant in the central part of the region (overlapping with cluster 2) and often adjacent to urban or even agricultural areas (Wcisło et al., 2002; Jarosinska et al., 2004; Stuczyńskiet et al., 2007).

The spatial distribution of Zn, Cd and Pb in soils of the four clusters is demonstrated on maps (Figure 22) and in Table 45. High concentrations of zinc in mobile forms are toxic to plants, although Zn has an antagonistic impact on cadmium, blocking its uptake by plants and absorption by mammals (Mishima et al., 1997). Zinc is an essential element for many physiological processes both in plants and mammals (Kabata-Pendias & Pendias, 2001). Whereas cadmium and lead do not have any physiological role and their intake by humans can lead to a dysfunction of different organs – the most commonly known is the impact of lead on brain function in children and that of cadmium on kidneys in adults (Webb, 1972; Crowe & Morgan, 1997; Hackley & Katz-Jacobson, 2003).

The majority of soils in cluster 1 meet the criteria for agricultural and urban use (class A and B), and only 11% of land falls into C class, which limits the land to industrial development – but not urban expansion – because of concerns about elevated concentrations of soil lead. These levels, however, may not necessarily be influenced solely by industrial emissions, but, at least to some extent the high concentrations of metals originating from geogenic sources related to the mineralogy of parent rock material, since cluster 1 is distant from industrial contamination sources that are found in cluster 2 (Terelak et al., 1997).

It is apparent that soils in cluster 2, primarily covering Upper Silesia are generally strongly affected by contamination with metals – over 70% of agricultural land meets class C criteria for cadmium and zinc, and is not suitable for agriculture and urbanization. With regards to lead in soils, class C land occupies as much as 85% of the cluster area. A considerable part of soils in cluster 2 (17%) are above class C criteria for Pb, which means that they are not suitable even for industry, according to the existing regulatory values. Historically, mining and smelting of non-ferrous ores were one the main types of industry in the region, and a major source of soil contamination. Nevertheless, even here, a part of metal contamination is driven by natural geological processes, as some of the soil's parent rock material originates from ore outcrops

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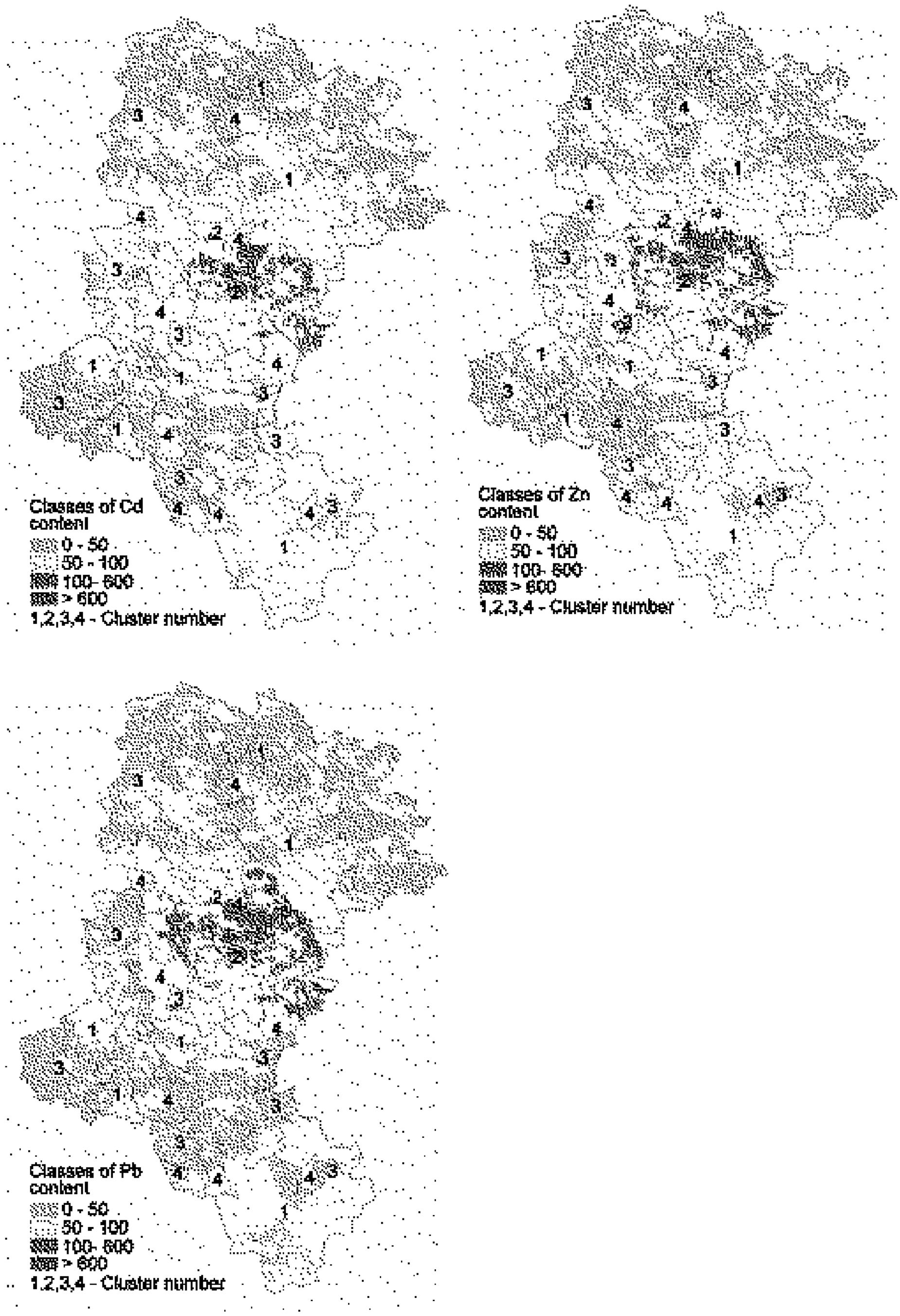

Figure 22. Distribution of cadmium, zinc and lead in agricultural soils (mg · kg^{-1})

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Table 44

Characterisation of soil contamination with Zn, Cd and Pb in Silesian clusters

		Cd (mg · kg^{-1})				Zn (mg · kg^{-1})				Pb (mg · kg^{-1})			
		A 0-1	B 1-4	C 4-15	>15	A 0-100	B 100-300	C 300-1000	>1000	A 0-50	B 50-100	C 100-600	>600
Cluster 1	**ha**	100521	110756	10348	0	101123	102264	18236	2	131333	65755	24209	328
	%	45	50	5	0	46	46	8	0	59	30	11	0
Cluster 2	**ha**	660	9848	26331	419	0	4213	26640	6405	0	5123	31511	624
	%	2	26	71	1	0	11	72	17	0	14	85	2
Cluster 3	**ha**	237587	81705	0	0	245053	72321	1918	0	292365	22746	4181	0
	%	74	26	0	0	77	23	1	0	92	7	1	0
Cluster 4	**ha**	58937	63705	1590	0	57045	62369	4791	27	80639	36875	6718	0
	%	47	51	1	0	46	50	4	0	65	30	5	0
Silesia	**ha**	397705	266014	38269	419	403221	241167	51585	6434	504337	130499	66619	952
	%	57	38	5	0	57	34	7	1	72	19	9	0

coming to the surface. Recently, secondary emissions from waste piles became an important metal contamination source, as direct emissions from industry are negligible (Gzyl, 1995; Wcisło, 2002; Stuczyński et al., 2007). Smelter waste piles are scattered in many locations within this cluster which is shown on land use classification map (Figure 23).

These zinc and lead waste piles are disturbing urban and agricultural landscapes leading to their fragmentation and exposure to wind blown, metal-rich particles escaping from barren surfaces (Figure 23). Contaminated soil in this cluster is an important source of exposure to metal dust and dietary ingestion through consumption of locally produced crops – e.g. in hobby gardens (Kucharski et al., 1994; Gzyl 1990; Gzyl & Marchwińska 1995; Dudka et al., 1995).

In cluster 3, almost 100% of soils meet the criteria for agricultural and urban land (class B). Moreover, a vast majority of soil cover is below the threshold for class A soils established for protected areas. In cluster 4, soil contamination with metals affects no more than 5% of agricultural soils, however, it is important to learn how this land is managed in the urbanization process – it can be hypothesised that most of urbanization took place in areas surrounding of industrial centres, and, in consequence, the exposure of the population to contaminants can be significant here.

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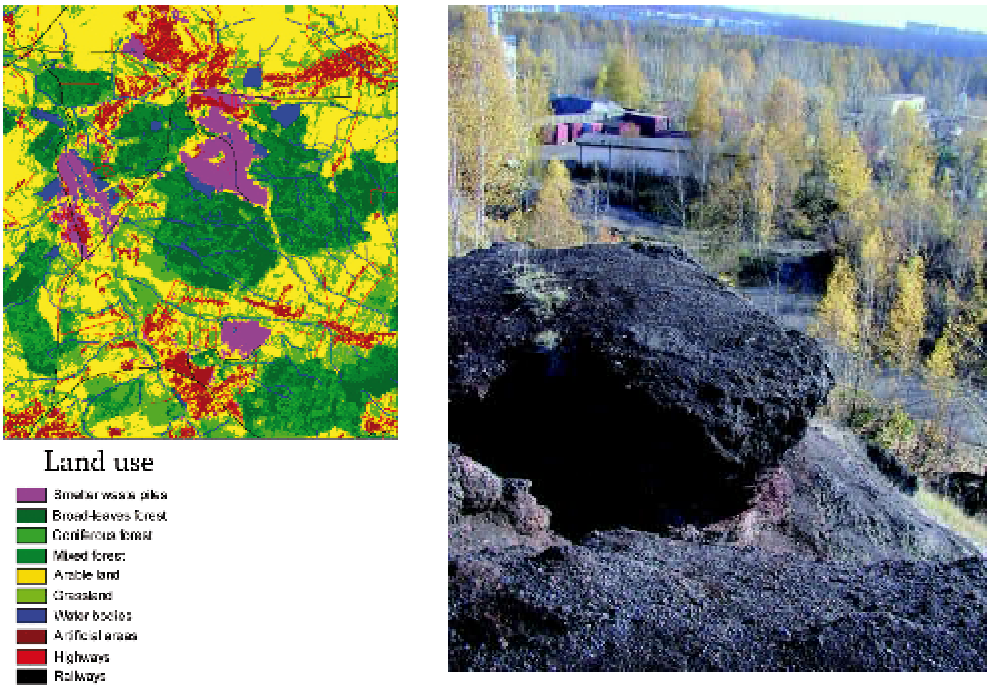

Figure 23. (A) Land use classification – part of Upper Silesia, urban agricultural areas neighbouring numerous smelter waster piles; (B) View of zinc and lead waste pile from former Waryński smelter 2002, in Piekary Śląskie

3.6.3. Development on agricultural land – soil contamination status

Recognizing that soil contamination in cluster 3 is marginal, further analysis of agricultural land change will be focused on other clusters, where soil contamination may pose an environmental and human health risk following the urbanization process. Zinc and lead are chosen as soil pollution indicators. Contamination with cadmium is indirectly accounted for by zinc distribution in the area of interest - these two elements are geo-chemically related and soil contamination with these metals spatially overlaps (Kabata-Pendias & Pendias, 2001), which is also evident in the Silesian region (Figure 22).

Arable and pasture soils, which have changed their functions represented mainly class A and class B land (Table 45).The transition indexes reflecting intensity of changes across different Zn content, with a few exceptions, range around 1, indicating that the shares of class A and B soils in converted land follow a general pattern of their distribution in agricultural land (Table 45). Forest expansion took place mainly on class A (3189 ha) and B (4033 ha) arable soils – accounting for 43% and 54% of flow, respectively (Table 45). Small areas of Zn class C arable and pasture soils (276 ha and 308 ha) were forested – the rate of this change on arable land is smaller than

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Table 45

Shares of different soil Zn content classes in various land use conversion types in cluster 1

Conversion type		Zn classes (mg · kg^{-1})			
		A 0-100	B 100-300	C 300-1000	1000-1660
Arable land into Forest and semi natural areas	ha	3189	4033	276	1
	%	43	54	2.99	0.01
	transition index	0.90	1.23	0.38	10
Pastures into Forest and semi natural areas	ha	1505	3290	308	0
	%	39	64	7	0
	transition index	0.74	1.21	0.88	0.00
Arable land into Artificial areas	ha	5371	4751	832	0
	%	49	43	8	0
	transition index	1.02	0.98	1.00	0.00
Pastures into Artificial areas	ha	773	1360	213	0
	%	33	58	9	0
	transition index	0.85	1.09	1.13	0.00

expected from the contribution of C class soils to agricultural land. The urban and industrial development on class C soils (for Zn) on arable and pasture land, acreage-wise, was quite substantial (832 ha and 213 ha, respectively), although it accounted for less than 10% of the expansion of artificial areas.

Regarding lead distribution in soils of transformed land, the majority of areas met class A or B criteria. A non-preferential conversion of arable and pasture land into forests and artificial surfaces was also observed on C class soils (Table 46). The conversion of arable land into built-up areas (1050 ha) was particularly sizeable, accounting for 10% of the total change in this direction – transition index 0.91. Given that more than 95% of this change concerns urban residential areas, current thresholds allowed for this function are exceeded in this case. A small acreage of strongly contaminated arable and pasture land was consumed by development - total of 21 ha (Table 46).

In the metal contaminated cluster 2, most of the forestation took place on class C land for Zn and Pb (Table 47-48), which is positive, as it leads to reduced human exposure, but it may lead to an increased eco-toxicological risk in forested habitats (Krzaklewski et al., 2004). With regards to Zn and Pb distribution in soils, most of the land flows into other functions took place in areas with a soil cover meeting class C criteria, although these transitions were not preferential and mirrored a pattern of Zn and Pb distribution in soils (Table 47-48). None of the converted areas represent class A criteria for soils, neither for Pb nor for Zn. The intensity of conversion of class C soils (both for Zn and Pb) into other functions, was proportional to their share in the land cover, as indicated by transition indexes approaching 1.

Urban development taking place mainly on class C soils can be explained by a limited choice in planning, as high levels of metal content in soils occur in vast majority of the area. In many locations, the contamination is not driven by industrial impacts only, but to a significant extent also by the natural background, associated with the

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Table 46

Shares of different soil Pb content classes in various land use conversion types in cluster 1

Conversion type		**Pb classes (mg · kg^{-1})**			
		A 0-50	**B 50-100**	**C 100-600**	**600-830**
Arable land into Forest and semi natural areas	ha	4136	2986	377	0
	%	55	40	5	0
	transition index	0.90	1.43	0.45	0.00
Pastures into Forest and semi natural areas	ha	1943	2595	558	7
	%	38	51	10.9	0.1
	transition index	0.72	1.42	1.00	2.50
Arable land into Artificial areas	ha	6982	2918	1050	4
	%	63	27	9.9	0.1
	transition index	1.03	0.96	0.91	10.0
Pastures into Artificial areas	ha	1096	966	267	17
	%	47	41	11	1
	transition index	0.89	1.14	1.00	25.0

Table 47

Shares of different soil Zn content classes in various land use conversion types in cluster 2

Conversion type		**Zn classes (mg · kg^{-1})**			
		A 0-100	**B 100-300**	**C 300-1000**	**1000-1660**
Arable land into Forest and semi natural areas	ha	0	86	1184	99
	%	0	6	86	10
	transition index	0.00	0.75	1.16	0.56
Pastures into Forest and semi natural areas	ha	0	209	615	134
	%	0	22	64	14
	transition index	0.00	1.10	0.98	0.93
Arable land into Artificial areas	ha	0	135	1496	564
	%	0	6	64	30
	transition index	0.00	0.75	0.86	1.67
Pastures into Artificial areas	ha	0	76	587	211
	%	0	9	67	24
	transition index	0.00	0.45	1.03	1.60

geological origin of the parent rock material - Zn and Pb ore outcrops coming to the surface (Terelak et al., 1997).

Unfortunately, a substantial acreage (534 ha) of heavily zinc contaminated soils, above the threshold for C class, was taken by urbanization and this flow was preferential – transition index 1.67. Similar, but even more preferential was the conversion of pasture land into artificial surfaces on soils above class C threshold for Pb, consuming 119 ha with a transition index of 3.25 and accounting for 13% of development on a pasture land (Table 49).

Assessing land use changes in cluster 2, it should be emphasized that a majority of the urbanization took place on soils exceeding current thresholds for metals, estab-

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Table 48

Shares of different soil Pb content classes in various land use conversion types in cluster 2

Conversion type		**Pb classes (mg · kg^{-1})**			
		A 0-50	**B 50-100**	**C 100-600**	**600-830**
Arable land into Forest and semi natural areas	ha	0	113	1246	10
	%	0	8	91	1
	transition index	0.00	0.73	1.03	1.00
Pastures into Forest and semi natural areas	ha	0	195	748	15
	%	0	20	78	2
	transition index	0.00	0.91	1.05	0. 50
Arable land into Artificial areas	ha	0	231	1957	7
	%	0	10.7	89	0.3
	transition index	0.00	1.00	1.01	0.30
Pastures into Artificial areas	ha	0	85	670	119
	%	0	10	77	13
	transition index	0.00	0.45	1.04	3.25

lished for urban land use function. It is evident that a certain health risk is involved in the expansion of built-up areas here. Most of the development on metal contaminated soils was not preferential, as their share in converted areas was very similar to their contribution in the entire soil cover. It is of vital importance to monitor current land developments, in order to check if regulatory values introduced in 2002 are effectively enforced. Apparently, in the past several decades, soil contamination was not a constraint for development, and risk aspects were not adequately taken into account in the planning process. On the other hand, urban expansion is difficult to avoid here, as there will always be a demand from the local population, which is one of the densest in Poland.

Toxicity studies conducted in Upper Silesia, comprised mainly of cluster 2, indicate a considerable accumulation of lead and cadmium in humans, as measured by concentrations of these metals in hair of the urban population (Nowak & Chmielnicka, 2000), as well as in blood (Osman et al., 1998; Jarosińska et al., 2004; Jarosińska et al., 2006). One of the adverse health effects observed, related to lead exposure, is a relatively high incidence rate of mild mental retardation (MMR) of Silesian children, which in 2001 was twice as high as in the reference European region (Jarosińska et al., 2006). Results of audiometric studies revealed an impairment of the auditory function in children in the Katowice district, caused by an exposure to lead, and reflected in elevated blood concentrations. Moreover, levels which cause these dysfunctions are relatively low, which indirectly indicates a high sensitivity to the existing sources of exposure to lead (Osman et al., 1998).

It seems that the recent toxicity studies cited above, identifying contamination impact on human health, did not consider soil as a major source, having a direct impact on blood levels of metals and their accumulation in other organs. Considering that today there are no excessive emissions from industrial installations, and the fact that

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Table 49

Shares of different soil Zn content classes in various land use conversion types in cluster 4

Conversion type		**Zn classes (mg · kg^{-1})**			
		A 0-100	**B 100-300**	**C 300-1000**	**1000-1660**
Arable land into Forest and semi natural areas	ha	1182	1171	119	0
	%	48	47	5	0
	transition index	1.02	0.96	1.25	0.00
Pastures into Forest and semi natural areas	ha	486	814	99	0
	%	35	58	7	0
	transition index	0.83	1.09	1.75	0.00
Arable land into Artificial areas	ha	4461	4815	296	0
	%	47	50	3	0
	transition index	1.00	1.02	0.75	0.00
Pastures into Artificial areas	ha	1043	1143	121	5
	%	45	49	5.8	0.20
	transition index	1.07	0.92	1.20	3.00

secondary emissions from waste piles may be substantial – even though their acreage is limited – the contamination of more than 85% of soil cover seems to be the best explanation for the health effects caused by metals.

In this light it is critical that effective policies are introduced to reduce the impacts on health and ecosystems through improved land management, which would not be limited to post-industrial sites, as is the current practice. Within the group of required measures the most urgent priorities are: the reclamation of waste piles generating fugitive dust, and limiting exposure pathways such as consumption of vegetables from backyard gardens.

In cluster 4, a distribution of class A and B soils (for Zn) within agricultural land changed into different functions is proportional to the contribution of these classes in arable and pasture land, as shown by transition indexes ranging around 1 (Table 49). Most of the conversions took place on these soils, and the split between A and B class soils was almost even (Table 49). Only a small acreage, between 4% and 8%, of different conversions considered in the study, represents class C land for Zn. The forestation of class C soils on arable and pasture land is more intense than expected from their share in the soil cover – with transition indexes of 1.75 and 1.6, respectively (Table 49). The urbanization of such land was limited, and consumed only 296 ha of arable land and 161 ha of pasture land, with their share in the expansion of artificial areas following the structural pattern of Zn distribution in agricultural soils. With regards to the distribution of lead in soils of agricultural land converted into other uses, usually over 50% or 60% of changes took place on class A soils (Table 49). Over 90% of all changes met class A or B thresholds. A more significant share of class C soils for Pb (14% and 195 ha) concerned pasture land converted into forests, and this is a

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preferential flow relative to the pattern of Pb distribution in pasture soils – transition index 1.73 (Table 50). The expansion of urban land on class C land for Pb consumed 339 ha and 196 ha on arable and pasture land, respectively. Considering that more than 80% of the change into artificial areas is accounted for by urbanization in this cluster, at least some part of the population is likely to be exposed to the risk associated with elevated levels of Pb in soils.

Summing up issues related to land use changes on contaminated soils, it is apparent that there is a significant exposure of the population to health risks associated with the expansion of built-up areas in the industrial cluster 2 of Upper Silesia – the majority of the development took place on land which does not meet regulatory values for urban use. This is mainly a consequence of the pattern of metal distribution in soils and a limited availability of class B soils suitable for development. It seems that soil has not been adequately recognized as a pollution source in terms of health risk, and most of the management and policy focus was given to direct emissions or to contaminated waste deposits. It is therefore crucial to conduct a health risk assessment for these areas, and if necessary, to stabilize metals in soils in order to reduce the risk of metal leaching into ground and surface waters, as well as ingestion of dust by humans and animals. The establishment and maintenance of a dense permanent vegetative cover on bare waste areas, brownfields and polluted agricultural soils adjacent to urban fabric, could help greatly to minimize fugitive dust movement and risk for metal environmental and health impacts (Stuczyński et al., 2007).

4. SUMMARY AND CONCLUSIONS

4.1. LAND USE CHANGE TRENDS, MECHANISMS AND MODELLING

Table 50

Shares of different soil Pb content classes in various land use conversion types in cluster 4

Conversion type		Pb classes (mg · kg^{-1})			
		A 0-50	**B50-100**	**C 100-600**	**600-830**
Arable land into Forest and semi natural areas	ha	1628	722	122	0
	%	66	29	5	0
	transition index	1.00	1.00	1.00	0.00
Pastures into Forest and semi natural areas	ha	601	603	195	0
	%	43	43	14	0
	transition index	0.72	1.34	1.73	0.00
Arable land into Artificial areas	ha	6097	3136	339	0
	%	64	33	3	0
	transition index	0.97	1.14	0.60	0.00
Pastures into Artificial areas	ha	1249	867	196	0
	%	54	38	8	0
	transition index	0.90	1.19	1.00	0.00

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In the light of this study, it is apparent that losses of agricultural land to supply space for urban and industrial development are strongly driven by economic factors, demographic structures and social conditions – these factors interact and control an attractiveness of a region for investment and its urbanization potential. An expansion of urban and industrial areas can be satisfactorily described as a function of a few variables such as GDP, population density, population growth, employment figures, or other closely related variables serving as surrogates for land use change drivers.

System dynamic modelling seems to be a useful tool, capturing complex processes that drive agricultural land use change. Ex-post analysis of agricultural land change into artificial surfaces for the period 1990–2000 shows that a dynamic model can explain close to 80% of observed flows at the aggregation level of a country. In the proposed modelling scheme, land use changes are calculated from regression equations, reflecting their relationships with socio-economic factors such as GDP, employment and demographic indicators. System dynamics is captured through feedbacks affecting GDP, which is influenced by migration processes – in such a way, the temporal evolution of the system is considered. Results of modelling exercises demonstrate that the complexity of land use change process can be retrieved by a relatively simple model, which is quite robust for a national-level analysis, forecasting the size of urban and industrial functions. Modelling changes in forest area as a function of socio-economic variables produces acceptable results at a resolution of major clusters and fails at lower aggregation level, such as for a country. This is likely due to the influence of local biophysical and economic factors playing a major role in decision making with regards to afforestation.

Predictions for 2020 indicate that an expansion of urban and industrial areas in the EU-15, relative to year 2000, will be 30%–40% higher as compared to most of the EU-10. Considering the larger size of these land use functions in the EU-15 in 2000, it is evident that the biggest losses of agricultural land are expected in the EU-15. A relatively small increase of urban areas predicted for new member states can be explained by migration to former EU-15 countries, as well as by negative demographic trends, regardless the fact that these economies demonstrate a considerable growth rate.

The largest increase of urban areas at the expense of agricultural land, relative to their size in 2000, is predicted for the Iberian Peninsula, Ireland, parts of France, the UK, Italy, Greece and a few regions in new member states. Among new member states such countries as the Czech Republic, Slovenia, Malta, Cyprus and Hungary will face the largest pressure on agricultural land as a consequence of economic developments. Area-wise, however, the largest urbanization pressure on agricultural land is forecasted for regions in Belgium, the Netherlands, Germany, the UK, Italy and Hungary. Since potential impacts of soil sealing related to changes in hydrological systems and loss of landscape diversity will concentrate in these regions, there is an urgent need to review existing polices to assess the efficiency of their protection.

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4.2. LAND USE CHANGES IN THE CONTEXT OF PROTECTING SOIL FUNCTIONS

An expansion of artificial surfaces at the expense of agricultural land, which potentially affects soil functions, concerned a relatively small number of European regions only – in the period 1990–2000. A vast majority of NUTS-x units analyzed do not represent any major preferential urbanization of high suitability land, organic matter rich soils, high water retention capacity soils, or highly erodible land. The preferential urbanization of arable land meeting these characteristics, indicative of an unsustainable use of soils, concerns the economically and socially weak industrial regions, comprised mainly of units located in new member states (cluster 2) – development meeting this definition represented 27% of built-up area expansion in the period in 1990-2000. In other regions, aggregated into clusters, a preferential conversions affecting soil functions, usually did not exceed 10% of total flows into urban areas (e.g. cluster 4). Management of land in Southern Europe (cluster 3) is the most sustainable and flows that are detrimental to soil functions account for a marginal percentage of artificial surface increases in the 1990–2000 period.

There were also preferential flows of agricultural land observed, which contributed to an improvement of soil functions through conservation of soil OM, improvement of water storage capacity and providing protection against erosion, due to forestation of poor quality and erodible land. These flows were particularly significant in cluster 2, where more than 35% of forestation concerns light texture soils, which are not suitable for agriculture, low in OM, or exposed to erosion processes. This, however, should not be interpreted as a full compensation of preferential conversion into artificial surfaces of valuable soil habitats, mentioned earlier, and their protection against urbanization is not sufficient. A preferential forestation of poor quality soils observed in eastern regions is likely driven by the low productivity of light texture soils.

It seems evident in the light of results presented in this study that the efficiency of soil protection policies varies significantly across Europe. Building on the best-quality land, which is suitable for crop production, on high water retention capacity soils, OM rich soils, or land exposed to erosion is much more common in economically and socially weak industrial European regions comprised mainly of new member states (cluster 2). In contrast, in the more advanced Western European economies, the preferential consumption of soil resources, which potentially results in an impairment of landscape soil functions, represents a share in urbanization even 3 times lower, as compared to the less developed regions. It is worth emphasizing, however, that most of the regions in the EU, including new member states, do not face a preferential sealing of soils, which is important for maintaining landscape functions.

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4.3. LAND USE CHANGE AND SOIL CONTAMINATION ASPECTS – – SILESIA CASE STUDY

Concentrations of metals in soils of agricultural land in Upper Silesia, which were transformed by urbanization during the last three decades, were far too high, relative to current thresholds established for urban functions. In fact, the choice for urban areas expansion in contaminated regions is limited as the amount of land meeting requirements is very small, often below 20% of the soil cover. A development on contaminated soils was not preferential as the share of contaminated land in built-up areas reflected their contribution to the total agricultural land. Although it also means that, so far, there were no efficient policies implemented to reduce the use of contaminated land for an urban development and to promote urbanization on land meeting regulatory values – currently, transition indexes characterizing rate of urbanization on clean soils in Upper Silesia are not much different from 1. In consequence, soil contamination leads to health impacts, confirmed by extensive toxicity studies, particularly affecting children.

New management strategies are needed for the area in order to minimize the existing health risk. These strategies should include a proper management of green areas, the introduction of wind erosion barriers and establishment of a permanent vegetative cover as necessary means to reduce a movement of contaminated dust and soil particles. A mitigation of impacts should involve spatial planning and reconsideration of zoning, taking into account the extent and spatial distribution of soil contamination. Leaving contaminated land in agriculture is not sustainable option either, as there is a food chain risk involved. The most severely polluted land should be forested. Industrial cropping systems, possibly with energy crops, could be a feasible alternative, however, such systems would need to consider reduction of dust movement during tillage operations. Combination of reduced tillage and permanent industrial crops could be an option. As regards metal waste piles, an application of good quality biosolids and lime could be a low cost alternative for top-soiling, effectively stabilizing metals and minimizing their environmental impact, particularly

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the movement of air born particles and leaching to ground and surface waters.

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ASSESSMENT AND MODELLING OF LAND USE CHANGE IN EUROPE IN THE CONTEXT OF SOIL PROTECTION

Abstract

Key words: land use change, soil protection strategy, modelling land use change, environmental impact assessment, organic matter, erosion, water retention capacity, land suitability.

This study is aimed at assessing how land use change, and in particular the development of artificial surfaces, affected agricultural land resources and soil functions in Europe in 1990–2000. An additional objective, following a historical analysis of land use change and its impacts on agricultural land resources, is to test the utility of System Dynamic Modelling as a simple tool for predicting future claims that will consume agricultural land in response to economic and population growth in the EU. Flows in land use functions are also analyzed in the context of soil and land quality to evaluate impacts on soil functions through selected indicators, and specifically to see how soil sealing (development of artificial surfaces) relates to the distribution of soil organic matter, water retention, soil erosion and the suitability of land for crops. Silesia, an industrial region of Poland, was used as a case study area in order to assess historical land use changes in the context of soil contamination and potential environmental and health impacts. Results of this study are an outcome of the EU-funded projects conducted within 6th European Framework Programme for Research and Technological Development – "LUMOCAP" and SENSOR", concerned with modelling of land use changes and impacts.

The model presented in this study is not spatially explicit and considers exogenous socio-economic drivers of a land use change. Dynamics are introduced by feedback between socio-economic variables and feedback between land use change. Feedbacks caused by biophysical variables are not included, as the model operates on an aggregated NUTS unit level, and not landscape level.

In the light of this study it is apparent that losses of agricultural land to supply space for urban and industrial development are strongly driven by the size of the economy, demographic structure, as well as by social conditions – these factors interact with each other and control the attractiveness of a region for investment and its urbanization potential. An expansion of urban and industrial areas can be satisfactorily described as a function of a few variables such as GDP, population density, population growth, employment figures, or other closely related variables serving as surrogates of land use change drivers. In the proposed modelling scheme land use changes are calculated from regression equations reflecting their relationships with socio-economic factors such as GDP, employment and demographic indicators. System dynamics are captured trough feedbacks affecting GDP, which is influenced by migration processes – in such a way the temporal evolution of the system is considered.

The results of the modelling exercise demonstrate that the complexity of land use change process can be retrieved by a relatively simple model, which is quite robust for a national level analysis, forecasting the size of urban and industrial functions. An ex-post analysis of agricultural land change into artificial surfaces for the period 1990–2000 shows that a dynamic model can explain almost 80% of observed flows at the aggregation level of a country.

Predictions for 2020 indicate that an expansion of urban and industrial areas in the EU-15, relative to year 2000, will be higher by 30-40%, as compared to most of the EU-10. Considering

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the larger size of these land use functions in the EU-15 in 2000, it is evident that the biggest losses of agricultural land are expected in the EU-15. A relatively small increase of urban areas predicted for new members states can be explained by migration to former EU-15 countries, as well as by negative demographic trends, regardless of the fact that these economies demonstrate a considerable growth rate.

An expansion of artificial surfaces at the expense of agricultural land, which potentially affects soil functions, concerns only a relatively small number of European regions in the period 1990-2000. A vast majority of NUTS-x units analyzed do not represent any major preferential urbanization of high suitability land, soils rich in organic matter, soils of high water retention capacity, or highly erodible land.

It seems evident in the light of the results presented in this study that the efficiency of soil protection policies varies significantly across Europe. Building on the best-quality land which is suitable for crop production, on soils of high water retention capacity, soils rich in OM , or land exposed to erosion is much more common in economically and socially weak industrial European regions comprised mainly of the new member states. In contrast, in the more advanced western European economies the preferential consumption of soil resources which potentially results in an impairment of landscape soil functions represents a share in urbanization even 3 times lower, as compared to the less developed regions. It is worth emphasizing, however, that most of the regions in the EU, including new member states, do not face a preferential sealing of soils important for maintaining landscape functions.

The concentrations of metals in soils of agricultural land in Upper Silesia which were transformed by urbanization during the last three decades were far too high, relative to the current thresholds established for urban functions.. In consequence, soil contamination leads to health impacts particularly affecting children, which is confirmed by extensive toxicity studies by other authors,. New management strategies are needed for the area in order to minimize the existing health risk. These strategies should include a proper management of green areas, the introduction of wind erosion barriers and the establishment of a permanent vegetative cover as necessary means to reduce the movement of contaminated dust and soil particles. A mitigation of impacts should involve spatial planning and reconsideration of zoning, taking into account the extent and spatial distribution of soil contamination. Leaving contaminated land in agriculture is not a sustainable option either, as there is a food chain risk involved. The most severely polluted land should be forested. Industrial cropping systems, possibly with energy crops, could be a feasible alternative. however, such systems would need to consider the reduction of dust movement during tillage operations.

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ANALIZA I MODELOWANIE ZMIAN UŻYTKOWANIA ZIEMI W EUROPIE W KONTEKŚCIE OCHRONY GLEB

Streszczenie

Słowa kluczowe: zmiany użytkowania gruntów, strategia ochrony gleb, modelowanie zmian użytkowania, ocena skutków środowiskowych, materia organiczna, erozja, pojemność wodna gleb, przydatność rolnicza.

Przedstawione studium ma na celu ocenę skali i wpływu zmian użytkowania przestrzeni, w tym zwłaszcza urbanizacji użytków rolnych, na funkcje gleb w Europie w latach 1990–2000. Ponadto przeprowadzono analizę danych historycznych charakteryzujących zmiany użytkowania, sprawdzając przydatność metod modelowania dynamiki systemów jako prostego narzędzia umożliwiającego przewidywanie skali przekształceń użytków rolnych, w następstwie rozwoju ekonomicznego i zmian demograficznych w Unii Europejskiej. Ocenę ekspansji urbanizacji i infrastruktury wykonano w kontekście przestrzennego zróżnicowania zawartości materii organicznej w glebach, ich zdolności retencyjnych, erozji oraz potencjału produkcyjnego (przydatności rolniczej). Podejście to pozwala na ocenę poziomu strat najcenniejszych zasobów przestrzeni rolniczej, prowadzących do zakłócenia funkcji gleb w Europie. Przykład Śląska jako regionu przemysłowego został wykorzystany do oceny zmian użytkowania gruntów rolnych w kontekście zanieczyszczenia gleb i potencjalnego wpływu tego zjawiska na środowisko i zdrowie człowieka. Badania były realizowane jako składowa część projektów „LUMOCAP" i „SENSOR", finansowanych przez 6 Program Ramowy Badań i Rozwoju Technicznego Unii Europejskiej, poświęconych modelowaniu zmian użytkowaniu ziemi i ich skutkom.

Model dynamiki procesu zmian użytkowania ziemi, opracowany w ramach badań własnych, odzwierciedla działanie czynników społeczno-ekonomicznych odpowiedzialnych za kierunek i tempo przekształceń. Dynamikę procesu kontrolują sprzężenia pomiędzy zmiennymi charakteryzującymi warunki społeczno-gospodarcze a zmianami funkcji w przestrzennym zagospodarowaniu. Sprzężenia związane z działaniem zmiennych opisujących warunki przyrodnicze przestrzeni nie są uwzględnione, biorąc pod uwagę fakt, że model działa dla obiektów zagregowanych do postaci jednostek administracyjnych (NUTS), a nie jednostek krajobrazowych.

Ekspansja terenów zurbanizowanych i przemysłu na terenach rolniczych może być wyjaśniona jako funkcja kilku zmiennych, takich jak poziom dochodu narodowego, gęstość zaludnienia, przyrost naturalny, zatrudnienie i innych powiązanych z nimi parametrów traktowanych jako korelaty czynników sprawczych przekształceń. W proponowanym podejściu do modelowania zmiany użytkowania liczone są na podstawie równań regresji obrazujących zależność tego procesu od zmiennych, takich jak: dochód narodowy, zatrudnienie i wskaźniki demograficzne. Dynamika zmian jest ujęta za pomocą sprzężeń mających wpływ na poziom dochodu narodowego, w tym zwłaszcza czynników kontrolujących zjawiska migracji. Uwzględnienie sprzężeń zwrotnych w modelu pozwala na odzwierciedlenie ewolucji dynamiki procesu przekształceń i popytu na ziemię w czasie. Uzyskane wyniki udowadniają, że złożoność procesów przekształceń przestrzeni rolniczej może być odtworzona za pomocą względnie prostego modelu, stosowalnego na poziomie krajów (NUTS-0). Analiza historycznych przekształceń przestrzeni rolniczej (Ex-post) dla okresu 1990–2000 wykazała, że opracowany model wyjaśnia blisko 80% fluktuacji zmian, w ocenie zagregowanej do poziomu krajów. Prognozy dla roku 2020 wskazują, że ekspansja urbanizacji i zabudowy przemysłowo-usługowej, w krajach dawnej piętnastki, liczona w stosunku do powierzchni zajętych przez te funkcje w roku 2000, będzie o

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30-40%większa, w porównaniu z większością nowych krajów członkowskich. Relatywnie niewielki przyrost powierzchni zurbanizowanych, w prognozie dla nowych krajów członkowskich, można wyjaśnić migracją do regionów atrakcyjniejszych pod względem ekonomicznym, jak również niekorzystnymi trendami w rozwoju demograficznym, niezależnie od faktu istotnego wzrostu gospodarek tych krajów.

W latach 1990–2000, rozwój zabudowy kosztem użytków rolnych, w sposób znacząco zakłócający funkcje gleb w krajobrazie, miał miejsce w stosunkowo niewielkiej liczbie regionów Unii Europejskiej. W zdecydowanej większości regionów na poziomie NUTS-x (połączenie jednostek NUTS-2 i 3 o podobnej wielkości) nie stwierdza się preferencyjnej urbanizacji obszarów gleb o największej przydatności rolniczej, gleb zasobnych w materię organiczną, o wysokich zdolnościach retencyjnych, bądź narażonych na erozję.

Uzyskane wyniki wskazują jednoznacznie, że skuteczność polityki ochrony gleb w poszczególnych krajach Unii jest silnie zróżnicowana. Ekspansja zabudowy na obszarach z glebami najbardziej przydatnymi do uprawy, o wysokiej pojemności wodnej, zasobnych w materię organiczną bądź na obszarach silnie narażonych na procesy erozyjne, jest zjawiskiem znacznie częstszym w regionach słabiej rozwiniętych pod względem wskaźników społeczno-ekonomicznych, do których należą głównie nowe kraje członkowskie. Stan ten kontrastuje z bardziej rozwiniętymi gospodarkami krajów Europy zachodniej, gdzie preferencyjna ekspansja zabudowy na glebach, których ochrona ma istotne znaczenie dla zachowania równowagi krajobrazu ma trzykrotnie mniejszy udział w przekształceniach, niż w regionach słabszych ekonomicznie.

Analiza procesów przekształceń na obszarach przemysłowych, wykonana na przykładzie Śląska, wskazuje, że w ciągu ostatnich 3 dekad rozwój urbanizacyjny często zachodził na glebach zanieczyszczonych metalami ciężkimi, na których przekroczone są obecnie obowiązujące granice zawartości cynku, kadmu i ołowiu. Zanieczyszczenie tych gleb metalami ma konsekwencje zdrowotne, potwierdzone w badaniach toksykologicznych, w tym zwłaszcza w odniesieniu do populacji dziecięcej. Stan ten wymaga wdrożenia odpowiednich strategii zarządzania przestrzenią, minimalizujących ryzyko zdrowotne, w tym utrzymania trwałej okrywy roślinnej na obszarach zanieczyszczonych oraz wprowadzenia naturalnych barier zapobiegających erozji wietrznej. Działania te są niezbędne w celu zmniejszenia emisji do powietrza pyłów metalonośnych i zanieczyszczonych cząstek gleb. Zapobieganie skutkom zanieczyszczenia winno także obejmować instrumenty planowania przestrzennego, w tym weryfikacji zasięgów poszczególnych funkcji, z uwzględnieniem przestrzennych uwarunkowań zanieczyszczenia gleb. Pozostawienie gleb zanieczyszczonych w tradycyjnym użytkowaniu rolniczym jest opcją sprzeczną z zasadami zrównoważonego rozwoju, ze względu na potencjalne zagrożenie dla łańcucha żywieniowego. Najbardziej zanieczyszczone obszary winny być zalesione. Uprawa roślin energetycznych i przemysłowych stanowi jedną z alternatyw dla obecnego systemu wykorzystania przestrzeni, przy czym technologie uprawy winny uwzględniać konieczność kontroli emisji zanieczyszczonych cząstek gleby do powietrza, podczas zabiegów uprawowych.

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