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Impact Assessment

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D4.3.1

Indicator framework for evaluating impacts of land use changes

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Abstract

Objectives

This report documents the selection process of indicators, which can be used to display the consequences of land-use changes in rural-urban regions on the case-study scale. The target of this report is to present the M4 PLUREL indicator framework for evaluating impacts on environmental, economic and social indicators (including lists of key indicators, description of the selection process, and fact sheets on the indicators - quantification, significance for rural-urban regions). The report documents the selected indicators and presents exemplary descriptions of those variables which have been successfully tested in PLUREL case study regions. The text starts with an explanation of the indicator framework, taking into account general requirements for indications and specific demands originating in the overall PLUREL concept as well as special features of the PLUREL approach. In the third chapter the procedural steps of indicator development are described. Thereafter the recent list of environmental (with relation to ecosystem integrity and ecosystem services), social and economic indicators is presented, and the tested indicators are explained on the base of regional analyses and scenario applications. Finally, future steps of indicator application are discussed.

Methodology

Indicator selection procedure:
- Development of an a priori theoretical model
- Derivation of a preliminary indicator list based on the theoretical model and discussions in workshops
- Analysis of indicator relations in an integrated indicator matrix
- Selection of key indicators based on matrix results and stakeholder feedback
- Data collection for key indicators
- Quantification of key indicators and visualization of results in form of maps and rural-urban gradients

Results

The final list of key indicators contains the following ecological, social, and economic indicators:

Ecological indicators:
Biodiversity potential
Carbon storage
Potential Evapotranspiration
Food provision
Energy provision
Water provision
Recreation
Climate regulation

Social indicators:
Population density

Settlement population density
Household size
Housing area per person
Mean age
Quality of life, regarding:
Air quality
Access to public green space
Availability and access to public transport
Availability of shopping facilities
Noise pollution
Area safety and security
House or flat suitability
Waste collection

Economic indicators:
Unemployment rate
Commuting distance
GDP
External costs green space
Costs carbon stock
Costs air pollution

Popular science description of main results

To assess the consequences of land use changes it is necessary to use a set of key variables which can be quantified. The application of such indicators in sustainability evaluation has to consider environmental, social and economic variables. In this report the strategy of selecting these variables is described, the indicators in hand are described and the methods how to quantify them are sketched and demonstrated.

Keywords

Indicator framework, Key indicators, DPSIR, environmental indicators, social indicators, economic indicators, ecosystem services, ecosystem integrity, Quality of life, rural-urban gradients

Classification of results/outputs:
For the purpose of integrating the results of this deliverable into the PLUREL Explorer dissemination platform as fact sheets and associated documentation please classify the results in relation to spatial scale; DPSIR framework; land use issues; output indicators and knowledge type.

Spatial scale for results: Regional, national, European	Regional
DPSIR framework: Driver, Pressure, State, Impact, Response	Impacts of land use changes
Land use issues covered: Housing, Traffic, Agriculture, Natural area, Water, Tourism/recreation	all
Scenario sensitivity: Are the products/outputs sensitive to Module 1 scenarios?	Outputs will be linked to MOLAND scenarios → indirect sensitivity to Module 1 scenarios
Output indicators: Socio-economic & environmental external constraints; Land Use structure; RUR Metabolism; ECO-system integrity; Ecosystem Services; Socio-economic assessment Criteria; Decisions	Ecosystem services, Ecosystem integrity, Socio-economic assessment criteria
Knowledge type: Narrative storylines; Response functions; GIS-based maps; Tables or charts; Handbooks	Narrative report, Tables, GIS-based maps, Graphs

How many fact sheets will be derived from this deliverable:	**10**

1. Introduction

This report documents the selection process of indicators, which can be used to display the consequences of land-use change in rural-urban regions on a case-study scale. The presented indicators are part of a conceptual framework which has been worked out by module 4.3 in cooperation with the indicator task force group.

The main objective of WP4.3 is to develop indicators to depict the impacts of spatially explicit land use changes using the MOLAND model, to select sustainability indicators and to quantify them for land use changes in selected case study regions. For this purpose, the results and targets of WP 4.3 contain the following points:

(1) spatially explicit land use change simulations for selected cases,

(2) an indicator framework for evaluating impacts of land use changes on environmental, economic and social indicators - output is a report including lists of key indicators, description of the selection process, and fact sheets on each indicator (quantification, significance for rural-urban regions)

(3) results of impact assessment for selected case studies - output is in form of tables, verbal descriptions, rural-urban gradients and spider grams for all dimensions of sustainability, and

(4) an analysis of the Quality of Life in rural-urban regions applied to selected case studies - output is in form of a questionnaire and results for the case studies, integrated into a preference simulator. Currently, empirical studies to feed the social indicators are carried out using the concept of Quality of Life and the method of an Adaptive Conjoint Analysis.

The target of this report is to present the M4 PLUREL indicator framework for evaluating impacts of land use changes on environmental, economic and social indicators. The deliverable is based on the milestone papers M 6.2.7 “Steps towards an integrated framework for PLUREL indicators” and M 4.3.8 “Integrated indicator matrix for rural-urban sustainability impacts”. The report documents the selected indicators and presents exemplary descriptions of those variables which have been successfully tested in PLUREL case study regions. After their test applications in MOLAND scenarios, the indicators will be integrated into the PLUREL XPLORER and the integrated Impact Analysis Tool (iIAT region). Due to the application of the Conjoint Analysis and its organizational consequences the analysis of several social key variables are only partly described. An overall documentation will be presented by ECA. Furthermore the economic calculations are based on the environmental analyses, calculating the costs of certain impacts. Therefore, and because of a partner transition from ZEW to UBATH, a detailed description of the economic variables has to be postponed.

This report starts with an explanation of the basic indicator framework concept, taking into account general requirements for indications and specific demands originating in the overall PLUREL concept as well as special features of the PLUREL approach. In the third chapter the procedural steps of indicator development are described. Thereafter the recent list of environmental (with relation to ecosystem integrity and ecosystem services), social and economic indicators is presented, and the tested indicators are explained on the base of regional analyses and scenario applications. Finally, the future steps are discussed, focusing on a completion of indicator quantification, their application and translation into a fast assessment approach and to the further elaboration of social and economic indices.

2. Conceptual requirements of the indicator framework

2.1 Indicator Requirements and PLUREL Objectives

The development of an overall PLUREL indicator set for the case-study scale of Module 4 has been carried out with reference to several conceptual requirements and constraints. On the one hand, there are **general methodological demands** which have to be considered. These items have been summarised in Tables 1 and 2, including information on the respective features of the developed PLUREL M4 indicators.

Table 1: General requirements for indicator sets from theoretical viewpoints (after Wiggering and Müller 2004) and respective features of the PLUREL case study indicator set

Good indicator sets should provide…..

- a clear representation of the **indicandum** (the indicated issue) **by the indicator**
  - ➢ main objective in indicator development (see individual indicator descriptions)
- a clear proof of relevant **cause - effect relations**
  - ➢ tested by indicator matrices (see Chapter 3.4)
- an optimal **sensitivity** of the representation
  - ➢ tested by slopes of gradients (satisfactory distinctions)
- information for adequate **spatio-temporal scales**
  - ➢ concentration on the case study scale with common spatial extents; time scale determined by MOLAND scenarios
- a very high **transparency** of the derivation strategy
  - ➢ tested by stakeholder feedback (see Chapter 3.3)
- a high degree of **validity** and representativeness of the available data sources
  - ➢ quantification based on official data (EU, local and national governments)
- a high degree of **comparability** in and with indicator sets
  - ➢ tested by case study comparisons (see Chapter 4.2)
- an optimal degree of **aggregation**
  - ➢ derived by working group and task force discussions (see Milestone 6.2.7)
- a good fulfilment of **statistical requirements** concerning verification, reproduction, representativness, validity
  - ➢ restricted usage of official statistical data (see indicator descriptions in 4.3)

To guide the selection of PLUREL indicators, it has been essential to develop an a priori theoretical model that outlines the different components of the phenomenon in question as well as the linkages and cause-effect relationships between them. This top-down approach, which begins with the elaboration of a theoretical framework, opposites the rather empirical bottom-up approach that refers to a listing of key issues considered to be important without developing a preceding theoretical concept but focussing on rapid data availability. By using the first approach, the recognition of knowledge gaps and omissions can be ensured even though it might not be possible to achieve a comprehensive account in a later stage depending on data availability or indicator applicability (Dale and Beyeler 2001, Wong, 2006, Niemeijer and de Groot 2008).

Table 2: General requirements for indicator sets from applied viewpoints (after Wiggering and Müller 2004) and respective features of the PLUREL case study indicator set

Good indicator sets should provide .....

- information and estimations of the **normative loadings**
  - ➢ reference to integrity, ecosystem service provision, quality of life (see Chapter 2.2)
- high **political relevance** concerning the decision process
  - ➢ optimized by stakeholder feed back (see Chapter 3.3)
- high **comprehensibility** and public **transparency**
  - ➢ optimized by stakeholder feed back (see Chapter 3.3)
- direct **relations to management** actions
  - ➢ adaptation to MOLAND scenarios (all key indicators)
- an orientation towards **environmental targets** (e.g. to aggregate by distance from target)
  - ➢ multi-target approach focussing on ecosystem services (see Chapter 2.2)
- a high utility for **early warning** purposes
  - ➢ application of the outputs of MOLAND scenarios (all key indicators)
- a satisfying **measurability**
  - ➢ usage of official and public data bases, qualitative alternatives (see Chapter 5)
- a high **degree of data availability**
  - ➢ basic constraint of practical indicator development procedure (see all individual indicator descriptions)
- information on **long – term trends** of development
  - ➢ Application of MOLAND scenarios (all key indicators)

Based on these items and the quality issues from Tables 1 and 2, project specific demands have to be taken into account. Referring to the **general objectives of the PLUREL project**, the final indicator set has to provide information and criteria, which

- o can be used in the developed *tools* to assist policy makers in analysing urbanisation processes and trends in the EU (e.g. to depict MOLAND scenario outputs, PLUREL Xplorer or iIAT Region),
- o are related to the *development of models* and strategies aimed at enhancing the understanding and handling of the multifunctional relationships between rural, peri-urban and urban land uses (e.g. ABM model inputs and outputs),
- o are capable of *describing the demands and competition for resources* (land/space, matter, energy, infrastructures etc.) *and functions* (residential, transportation, environmental and recreational services, food supply chains etc.) of rural-urban regions,
- o can *characterise the outcomes of land use scenarios* for rural-urban regions in Europe, and in doing so, enhance understanding of the economic, social and natural driving forces, including migration patterns, behind the growth and shrinkage of urban and peri-urban areas in Europe, and derive strategies for a more sustainable development of these areas,
- o will be used to synthesise the results into a generic *Sustainability Impact Assessment Tool* for the rural-urban relations (iIAT-Region),
- o will *enhance cooperation and communication* between policy makers, stakeholders, planners and researchers.

To fulfil these objectives, several **conceptual problems** have to be solved. These are related to the following tasks:

- o *<u>Combining the scales of PLUREL's modules:</u>* The constitution of the PLUREL working scales allows to investigate the problem of scaling and scale interactions and to apply the respective outcomes. While M2 preferably works on a broad, European scale, M4 is concentrating on the case study regions and tries to derive regional functions out of local scale models. Therefore, multiple aspects of the

RUR-relationships can be investigated, and the results of the scale specific activities can be compared, distinguished and combined.
Furthermore, scale invariant variables can be distinguished from parameters with more narrow spatial and temporal extents. This work will be supported by a close cooperation, i.e. with M5 and M2, whereby the response functions (M2), the indicator matrix (M4) and the iIAT algorithms will be checked for similarities, interrelations, and for the potential of joint cross-scale utilization of variables and functions.

- *Integrating different assessment approaches:* The basic approach of this indicator system includes focal items developed in Module 4 (quality of life, ecosystem services, economic assessments) which are conceptually correlated to the land use functions of Module 2. Furthermore, an intensive literature review has been conducted in order to facilitate a broader discussion on indicators. Approaches derived out of the literature review include for instance Multifunctionality, Land Use Functions, Sustainable Development Indicators, and European Assessment Criteria. The fields of economic, social and environmental issues of sustainable development are considered as well as the recent iIAT approach in PLUREL. The DPSIR scheme has been applied for structuring the indicator list. Special consideration has been paid towards the Land Use Functions of the EU Integrated Project SENSOR (Table 3). They are represented in the proposed list, with the exception of “cultural identity”, because this item seems to be very hardly transferable into quantified units.

Table 3: Focal SENSOR land use functions as constituents of the indicator system (SENSOR Newsletter No 4, 2006).

• Provision of work • Human health • Non land based production • Cultural identity • Provision of abiotic resources • Habitat biodiversity • Ecosystem processes • Land based production • Infrastructure, mobility

- *Representing the overall project concept in the indicator system:* As Figure 1 shows, the basic indicator model is an application of the DPSIR model to the recent general scheme of PLUREL’s product chains. This adaptation makes it possible to quantify the basic project components on both working scales by potentially distinct indicator sets and algorithms. Thus the consequences of management decisions or land use related policies can be depicted with regional as well as international references. Figure 2 illustrates the respective focal indicanda (the indicated issues) in the indicator systems of both PLUREL scales.

  The DPSIR (Drivers – Pressures – State – Impact – Response) model that has been developed by the European Environmental Agency (EEA, 1995; Holten-Andersen et al., 1995) is a framework that provides a “logical way of conceptualising the chain effect of human activities on the changing state of our environment” (Wong, 2006). It offers a possibility to classify indicators according to their role as human-induced drivers, resulting in environmental pressures and impacts and response indicators of the human system. Besides the EEA, also the OECD, the United Nations and several national projects have used the DPSIR model as a framework to develop sustainability indicator sets.

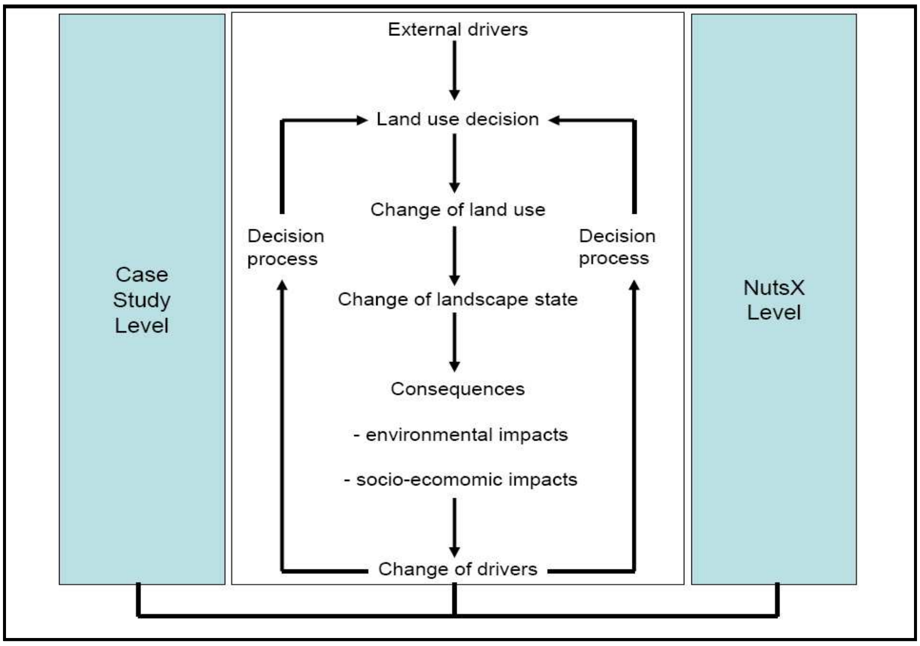

Figure 1: Basic outline of the central indicator model. The fundamental conceptual key issues are positioned in the middle of the scheme. They will be represented by indicators from both working scales, thus different decision makers can apply the indicator system.

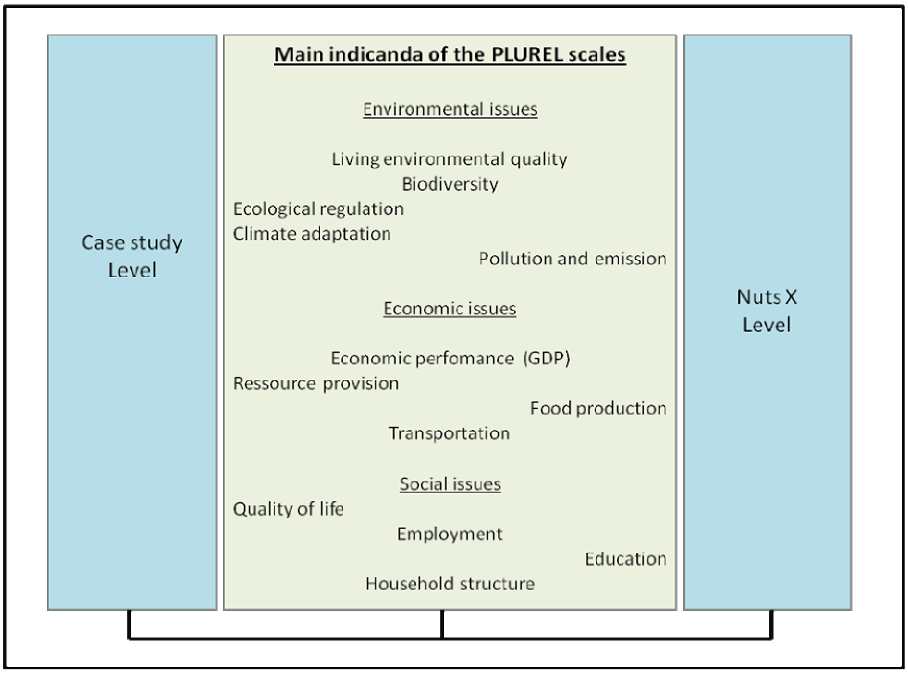

Figure 2: Main indicanda (indicated issues) on the two project scales of PLUREL; the distinction is mainly due to the respective scales of potential decisions and management measures and to data availability.

- *Indicating spatial interrelations:* The present indicator set provides values which can be measured, derived or estimated in urban areas as well as in suburbs or rural areas. To represent the spatial interrelations between these areas, gradients and the interrelated flows of important systems components (see Figure 3) are used to find regional ratios. Also aggregated and composite indicators can be represented on the base of spatial RUR-gradients. Doing this, the land use gradients (see for instance Figure 4 or Figure 5) are selected as a guideline to characterise the spatial distributions of ecosystem/landscape states in dependence of their distance to urban centres, resulting in aggregated indicator maps of the selected variables. These components will be quantified on the base of the typical land cover composition within the respective concentric sub-areas. Consequently, it is also possible to assign specific scenario conditions to specific positions in the gradient scheme.

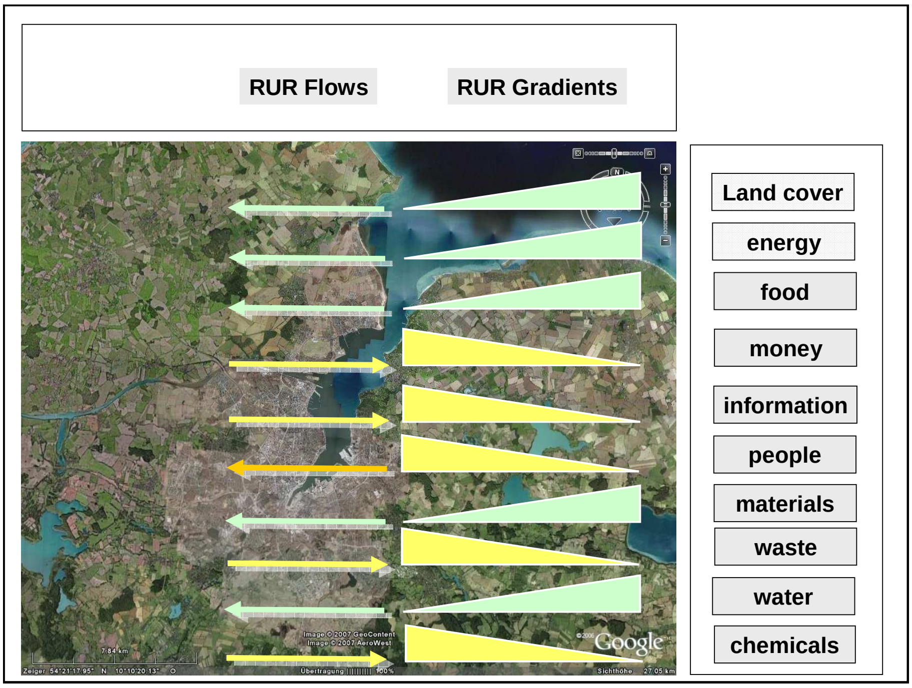

Figure 3: Selected urban-rural interrelations representing spatial gradients of key criteria and the respective flows

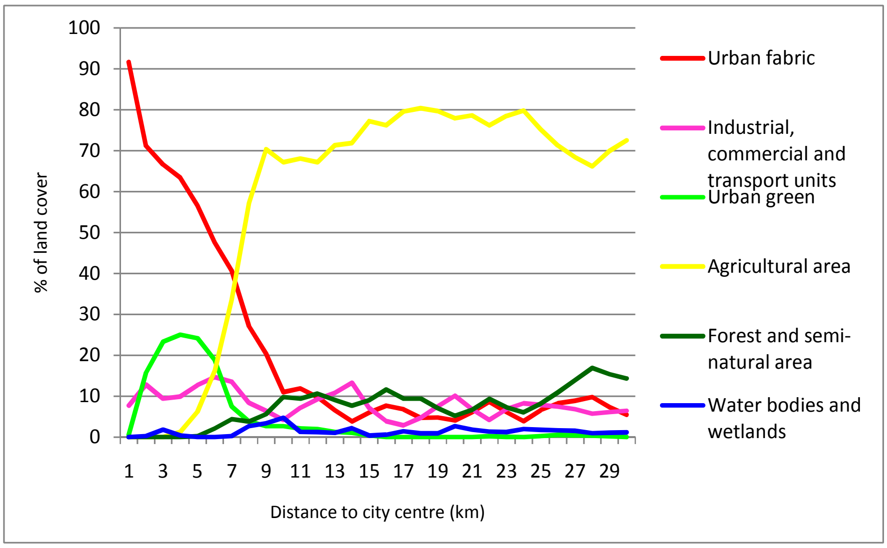

Figure 4: Rural urban land cover gradients for the case study of Leipzig, basing on the Corine Land Cover map of the year 2000.

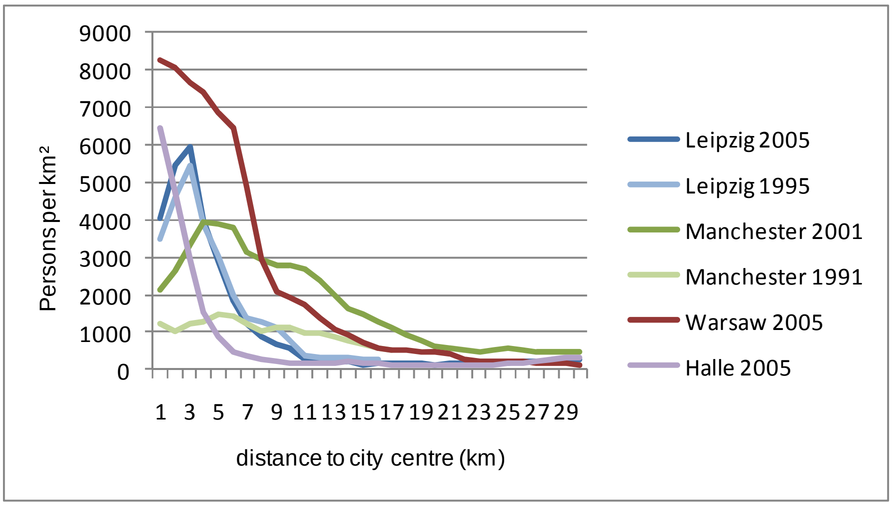

Figure 5: Spatial gradient of population density for the case studies of Leipzig, Halle, Manchester and Warsaw, showing the decrease of population density in concentric rings around the city centres. Data sources are population data on local district and municipality level from local and regional statistical agencies.

2.2 Special Features of the PLUREL Indicator Set

In comparison with other indicator sets the proposed system of variables is based on some new approaches. These concepts will be illustrated in the forthcoming paragraphs.

Landscape based application of "ecological integrity"

To characterize the ecological state of the investigated ecosystems and landscapes, the aggregated indication of *ecological integrity* has been applied in PLUREL. In this approach, structural, functional and organizational features of ecological systems are presented on a highly integrative, theory-based level, providing a holistic measure of the respective environmental conditions.

The term "ecological integrity" has been introduced by Leopold in 1944 to characterize the stability of biotic communities. In relation with the US Clean Water Act, it has been made operational by Karr and Dudley (1981), i.e. for the indication of aquatic ecosystem states. Subsequently, the concept of "integrity" has been developed e.g. by Woodley et al. (1993), Westra and Lemons (1995), Crabbé et al. (2000) and Barkmann (2002). In some of these interpretations integrity is related to the idea of wilderness, other authors refer to a social value perspective, and in a third group integrity represents a complex systems approach, which is based upon variables of energy and matter budgets and structural features of ecosystems (Barkmann et al. 2001). With reference to "ecosystem health", integrity can also be applied to recognise the human component (Rapport 2003), related to ecosystems that are manipulated and modified for the purpose of supporting human societies. In these systems, landscape management activities provide constraints which reduce the degrees of freedom for the (natural) processes of ecological self-organization.

The proposed interpretation of integrity is based on the sustainability principle: Taking into account the focal ideas of this concept, it is possible to use the following formulation for the ecological components of sustainable development: "Meet the needs of future generations" means "keep available ecosystem services on a long-term (inter-generational) and broad scale (intra-generational) level". To realize these multiple services, the supporting functions of ecosystems (Millennium Assessment 2005) have to provide an optimal performance, which is represented by a high degree of integrity.

Barkmann et al. (2001) have defined ecological integrity as a management target for the preservation against non-specific ecological risks. Consequently, the underlying management goal is a preservation and support of those processes and structures, which are essential for the ecological ability for self-organisation. This target is also applicable in cultivated landscapes and the corresponding criteria can be used in any ecosystem, reflecting the distinct constraints imposed by the actual land use structures.

In ecosystem theory there are several approaches (see Jørgensen 1996, Müller 1997, Jørgensen and Müller 2000, Ulanowicz 2000) that are highly compatible with the theory of self-organisation. The consequences of these concepts have been condensed within the orientor approach (Müller and Leupelt 1998, Bossel 1998, 2000), a systems-based theory about ecosystem development, which is founded on the general ideas of non-equilibrium thermodynamics (Schneider and Kay 1994, Jørgensen 1996, 2000, Kay 2000) and network development (Fath and Patten 1998, 2000) on the one hand and succession theory on the other (e.g. Odum 1969, Dierssen 2000).

The theories assume that ecosystems as self-organised entities are capable of creating structures and gradients if they receive a through flow of exergy (usable energy, or the energy fraction of a system which can be transferred into mechanical work, see Jørgensen 2000). This “high quality” energy fraction is transformed within metabolic reactions, producing non-convertible energy fractions (entropy), which are exported into the environment of the system. As a result of these energy conversion processes, gradients are built up and maintained, leading to ordered structures and storages of the imported energy within biomass, detritus and information as well as growing degradation of the applied gradients, which is necessary for the maintenance of the system (Schneider and Kay 1994).

Hence, throughout the complexifying (natural) development of ecosystems there are certain characteristics, which are increasing steadily and slowly, developing towards an attractor state which is restricted by the specific site conditions and the prevailing ecological functions (Holling 1986, Gunderson and Holling 2002). These principles have many consequences on ecosystem features. For instance, the food web will become more and more complex, heterogeneity, species richness and connectedness will be rising, internal flows are optimized, nutrient loss is reduced and many other attributes will follow a similar long-term trajectory throughout an undisturbed ecological development.

To apply these theoretical findings in practice, the selected indicators have to be represented by variables, which are accessible by conventional methods. Within this step, the number of indicators has to be reduced as far as possible. Thus, many ecosystem variables cannot be taken into account, but a small set, consisting of the most important items, (which can be calculated or measured, in many local instances), is what we have to look for. This set must be accessible in comprehensive monitoring networks (Müller et al. 2000, Wiggering and Müller 2004). The resulting focal components of ecosystem properties and functions can be summarised to: a) ecosystem structures (abiotic/biotic diversity or heterogeneity) and b) ecosystem functions (energy flows/balances, water flows/balances and matter flows/balances). For a detailed justification see Müller (2004 and 2005). The resulting general indicator set for ecosystems or landscapes states in terrestrial environments is shown in Table 4, including the respective PLUREL indicators.

Table 4: Proposed indicators to represent ecological integrity of ecosystems and landscapes. If any of these parameters are not available, other variables may be chosen to represent the respective indicandum. The respective PLUREL variables are listed as well, indicating those indicators which are still in the quantification procedure by *.

Orientor group	**Indicandum**	**Exemplary indicators**	**PLUREL indicators**
Biotic structures	Biodiversity	Number of selected species	Biodiversity potential
Abiotic structures	Biotope heterogeneity	Index of heterogeneity	Landscape diversity*
Energy balance	Exergy capture Entropy production	Gross or net primary production Respiration Output by	Net primary production*

	Metabolic efficiency	evapotranspiration and respiration Respiration per biomass	CO_2 production and sequestration*
Water balance	Biotic water flows	Transpiration per evapotranspiration	Evapotranspiration
Matter balance	Nutrient loss Storage capacity	Leaching, e.g. of nitrate Soil organic carbon Intrabiotic nitrogen	Carbon storage

Figure 6 shows an application of this indicator system in two neighbouring ecosystems in Northern Germany which have been used identically 100 years ago. Thus, the consequences of agricultural land use can be found in the following characteristics: The biomass production (exergy capture, indicated by gross primary production in this case) of the arable land system is much higher than in the forest. The structural items, biodiversity (no. of plant species) and heterogeneity (heterogeneity index) provide higher values in the forest ecosystem, and also storage capacity (in this case indicated by carbon and nitrogen soil storage) and the nutrient retention capacity (nitrogen leaching) of the maize ecosystem is reduced. The efficiency measures (biotic flows and metabolic efficiency) also show much higher values in the forest while the exports of non-usable energies (entropy export – soil respiration) are essentially the same in both ecosystems.

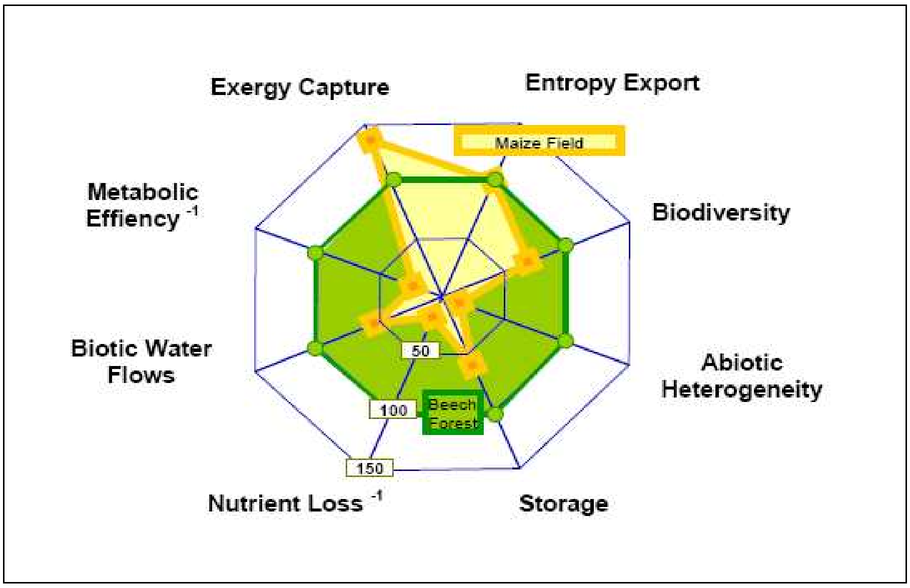

Figure 6: An example for the application of integrity indicators: Comparison of a beach forest and a neighbouring maize field in the Bornhöved Lakes District, N. Germany. From: Burkhard and Müller (2008)

Which is the relevance of integrity changes in urban-rural gradients? A literature review reveals the most important effects of urbanisation and land use change in rural urban regions on ecosystem integrity.

Especially the water cycle is changed through the sealing of soils, the canalization network and the small amount of vegetation cover in urban regions, which is often characterized by a low leaf area index (Pickett et al., 2001). These factors lead to a lower groundwater recharge, higher surface run-off and lower evapotranspiration, the latter being an important cause for the existence of the urban heat island (Pickett et al. 2001, Wessolek

2008). The impacts of urbanisation and urban sprawl to the water cycle have a consequence for the provision of clean drinking water, the microclimate regulation and the flood retention capacity (Haase and Nuissl, 2007).

Also nutrient cycling in ecosystems is heavily altered by human activities in rural urban regions (Faerge et al. 2001, Warren-Rhodes and Koenig 2001) which is of primarily importance for ecosystem integrity as nitrogen, one of the most important nutrients, is a key element controlling the species composition, dynamic and functioning of ecosystems (Vitousek et al. 1997). The uptake of NO_3^- and NH_4^+ by plants in rural areas is often not in balance with the high input of fertilizer and manure on agricultural areas, leading to nitrate leaching and NH_3 emissions to the atmosphere.

The same misbalance between plant uptake and fertilizer input is valid for phosphate (Odum, 1987). It is therefore questionable if the rural hinterlands of cities are sinks or sources for nitrogen and phosphorous, depending on land use and fertilizer input. A study of Faerge et al. (2001) about the nutrient balance of Bangkok demonstrates that the city is a sink of phosphorous, but nitrogen inflow via food and nitrogen outflow via the Chao Phraya River are almost in balance. Baker et al. (2001) found that approximately 90% of nitrogen and phosphorous inputs in the Central Arizona-Phoenix ecosystem are human-mediated and do not leave the system but accumulate in municipal and industrial waste sites, agricultural soils and groundwater pools. The authors argue that low levels of nutrient recycling in the study area highlight the lack of synergy that exists between urban centers and their hinterlands, caused among others by the small percentage of food that is produced in the local rural hinterland (Baker et al. 2001). This observation also counts for European cities, one example being London, where the origin of 81% of the consumed food lies outside the UK (Chatered Institute of Wastes Management 2001 in Warren-Rhodes and Koenig 2001). Additionally, cities are sources for nitrogen compounds due to the NO_x emission by traffic and industrial processes that exhibit an additional fertilizer for plants in urban and rural areas.

Another aspect of ecosystem integrity is the carbon stock and cycling in soils, plants and the atmosphere. Concerning the carbon in soils, urban land take greatly modifies soil carbon pools and fluxes proved by a significantly higher organic carbon density in urban soils than in rural soils (Pouyat et al. 2002). Also the carbon fluxes to the atmosphere are heavily affected by urbanisation. Pataki et al. (2007) quantified the effects of urbanisation and land use on the local carbon cycle along an urban rural gradient in the Salt Lake Valley, USA. They found a steep gradient of CO_2 concentration from the city centre to the rural hinterland with a comparably higher anthropogenic contribution of atmospheric CO_2 in the city centre and a comparably higher contribution of biogenic respiration to atmospheric CO_2 in the rural region. Of course, cities are a source of CO_2 due to oil and fuel combustion, natural gas combustion and CO_2 from biogenic origin (Clark-Thorne and Yapp 2003, Koerner and Klopatek 2002). The rural hinterlands can be both, a source or sink of CO_2, depending on the type of ecosystems (e.g. state of succession, type of vegetation, soil respiration) and the energy consumption of the rural population.

The named nutrient and matter cycles are important for many different ecosystem services such as the provision of food, clean water, clean air and the CO_2 sink function of ecosystems.

Conceptual linkages basing on ecosystem services

Recently the concept of ecosystem goods and services (which are jointly called ecosystem services) has demonstrated a rapid conceptual development at the interface of society and nature. Basing on the “functions of nature” (e.g. de Groot 1992), ecosystem services are “the benefits people obtain from ecosystems and the processes that support the production of ecosystem goods” (Millenium Assessment 2005). They result in “the benefits of nature to households, communities, and economies” (Daily 1997) as “components of nature, directly enjoyed, consumed, or used to yield human well-being” (Boyd and Banzhaf 2006). Generally three classes of ecosystem services are distinguished (see also Table 5): Provisioning services (goods produced or provided by ecosystems), regulating services (benefits obtained form regulation processes in ecosystems), and cultural services (non-material benefits obtained from ecosystems).

Since the controversial paper of Costanza et al. (1997) the basic ideas of the ecosystem service approach have been assumed by various international endeavours, such as the Millennium Ecosystem Assessment (MA 2005), the Ecosystem Approach of the UN Commission on Biodiversity (CBD, see http://www.cbd.int/ecosystem/sourcebook/), the International Union for Conservation of Nature (e.g. Smith and Maltby, 2008), or the European Environmental Agency that seeks for an environmental-economic accounting system "beyond GDP" (see http://www.eea.europa.eu/highlights/beyond-gdp) with ecosystem services in its focus. Recently, the COP 9 conference of the CBD (Bonn, May 2008) has stressed the high demand for substantiated statements about the economic costs of biodiversity loss (e.g. Sukhdev 2008). To summarize, the conceptual implementation of the approach into environmental and sustainability policy is steadily increasing.

Table 5: Overview of considered ecosystem goods and services (list after Millennium Assessment 2005)

Provisioning Services	**Regulating Services**	**Cultural Services**
Goods produced or provided by ecosystems	Benefits obtained from regulation of ecosystem processes	Non-material benefits obtained from ecosystems
Food - Crops - Livestock - Capture Fisheries - Aquaculture - Wild Foods Fiber - Timber - Cotton, hemp, silk - Wood Fuel Energy Genetic resources Biochemicals Freshwater	Air Quality Regulation Climate Regulation Erosion regulation Nutrient regulation Water purification Disease regulation Pest regulation Pollination Natural Hazard regulation	Spiritual and Religious Values Knowledge Systems Educational Values Inspiration Aesthetic Values Social Relations Sense of Place Recreation and Ecotourism

In M4, the environmental impacts will be indicated by the provision of ecosystem services as a function of modified state variables (integrity). The applied methods have been sketched in the milestone paper M4.3.7. The focal investigated services are

- food provision
- energy provision
- water provision
- climate regulation
- recreation

On the basis of the respective indicator characteristics the corresponding economic and social values will be derived to find new ways of representation of the overall impacts in rural-urban regions.

Applying the gradient approach for the indication of structures, functions, and metabolisms

In another theory-based attempt the distribution of relevant landscape features will be investigated by spatial statistical methods. Here, the countable differences of characteristic features between urban, suburban and rural areas are understood as gradients which provide potentials for flows between the spatial units. The "gradient paradigm" that is used to analyse the rural-urban relationships with respect to the above mentioned landscape/ecosystem characteristics is seen as a very useful concept by various authors (Whittaker 1967, Austin 1987, McDonnell and Pickett 1990). It deals with the degree of environmental change in space and its effect on ecological structures and functions (Roberts 1987). As we can find extremely steep gradients between the densely populated urban core and its hinterland, the gradient paradigm is a suitable tool to relate spatial heterogeneity caused by urbanisation with ecological processes in rural urban areas (McDonnell and Pickett 1990, Luck and Wu 2002).

Spatial gradients of land use (see Figure 4) are not only tied to the provision of ecosystem services, but also to population density gradients (see Figure 5) and gradients of different types of economic activity. To support the living standard of the urban population as well as their economic activities, cities need imports of food, energy, water and materials which are transformed and degraded in the cities and then partly exported, partly accumulated, changing the stock of materials and substances in the cities. In other words, cities are open systems, just as ecosystems, that need a constant input of usable energy (exergy) and matter to guarantee their functioning and internal order. The flow of components of this "urban metabolism" are, among others, dependent on land use and land cover in the rural urban region and have important impacts on its sustainability.

Nowadays, trade allows European cities to exist and grow independently from the ecological productivity of their hinterlands, but the dependency of European cities on global trade also means that the European urban population lives on the cost of the "carrying capacity" (Rees, 1996) of distant regions by importing ecosystem goods and services and exporting entropy to other parts of the world, where food production for the industrialized world causes deforestation, habitat and biodiversity losses, soil erosion and pollution. The increasing transport volume and transport distance of goods and people result in rising energy consumption and pollution (Kennedy et al., 2007). Hence, to assess the sustainability of a European city region, it is essential to analyze the characteristics of the urban metabolism in order to find out, how strong and in which ways modern European cities are linked to their hinterlands nowadays, which strongly depends on the land use in rural areas.

Therefore, the spatial differences of land cover items, food production and consumption, energy provision and degradation, material stocks and utilizations, water provision and usage, etc. are used to characterize the interrelations between urban centres and their hinterlands, comparing the provision and demand of the investigated regions.

These investigations will be used to characterise the case study areas and to distinguish different RUR types, to derive the gradients of focal indicators, and to show the spatial consequences of scenario outcomes.

Integration of ecological and social indicators

In PLUREL social indicators are an important set. In contrast with the ecological indicators, for example, or other types which are non-living and associated with the rural-urban region, social indicators involve people who react to changes in land use by making decision such as to move. These movements may be restricted to changing residential location when the perceived environmental quality decreases as a result of land use change – within the RUR – or they may involve significant migration not only between RURs within the same country but between countries within Europe or from outside Europe to Europe. These movements themselves are drivers of land use change (demand for more housing etc) and the resulting changes in population (increase in one area, decrease in another) exert a pressure on land use for which a response function is needed. Some of these drivers relate to job availability, educational opportunities, service availability etc (leading to rural depopulation in rural regions for example). Other aspects of social factors for which indicators are needed can be described using widely available statistics at a Nuts 1 or 2 level or below, such as population change and density (indicating a change in function if not of land use type, such as from single occupancy houses to multiple-occupancy flats, which places pressure on urban resources), numbers of doctors per 1000 of population (a decline of which in rural areas may indicate a lower quality of life), household structure (such as number of single households of older people or younger people, showing a change in the demographic structure and the demand for services). These statistics can show how changes in land use can affect social factors leading to changes in quality of life.

At a case-study regional level quality of life is well represented by a combined indicator called residential choice. This is based on the idea that different factors affected by land use change combine in different ways to increase or decrease the quality of life for people living in a particular place. There is a threshold level of the decrease of these factors in different combinations which cause people to move house because their perceived quality of life has decreased too far (assuming they have the economic freedom to move, that is). However, people are not all alike and they have different perceptions of what factors are important for QoL. This can depend on their "lifestyle group" or "tribe" (a description based on their preferences from different things leading them to prefer different places to live, for example people who prefer the urban life of the city centre or those who want a quiet rural retreat) and their life-stage (people with young families may have different priorities to young singles or older retired people for example). Thus, at the level of the RUR, a simple and crude indicator applied to everyone will miss many subtleties about the way that the population will respond to land use change and its resulting effect on the living environment.

Thus, in PLUREL a special approach is being used, based on a conjoint study.

Quality of life and choice processes for house location

As noted above, the attractiveness of a given place for habitation is connected to the QoL it has to offer (such as green space, air quality etc). However, each of the factors involved in making a place attractive is valued differently by the different types of people likely to live or move there. Each may play a different role in configuring how attractive a place is for living.

People's preferences for where to live depend on a series of factors, some that can be linked to their demographics, some to do with their lifestyle choices – including their environmental attitudes to, e.g. transport (using bicycles and public transport or preferring cars) or conservation (wanting to protect green areas or recycle waste) and consumer habits such as preference for organic produce, being keen on consumer goods etc. Changes in the scenario in which each person or group of people (tribe) lives will affect their choices and the importance they place in each attribute they take into account when making choices.

Finding out how different aspects of a residential area are valued by different groups of people in a context of choice is expected to help predict their behaviour when faced with changes in those areas. These changes can follow trends laid out in forecasted scenarios constructed and presented by Module 1.

As the scenarios propose, changes can take different directions and occur over varying timeframes. The changes should be reflected in a number of indicators, and affect residents in different and synergistic ways. The effect of

land use changes, such as an increase in traffic noise or an decrease in green space, will be felt by residents through time and tolerated until a tipping point occurs, a threshold after which they decide to relocate, if they have the means and freedom to do so.

The set of indicators used for this refers to aspects of residential environments that are perceived by residents in ways that will mean different standards of QoL to each of them. Many of these factors are weighed up when residents are faced with the decision of staying or relocating and where to move to. However, the choice process involved does not happen by isolating these factors and analysing them individually. As in most known choice situations, properties of the elements subject to choice are assessed in conjunction with each other, through the tradeoffs people are prepared to make among those properties. The factors chosen, which emerged from review of several indicator sets include the accessibility of green space, air quality, noise levels, perceptions of risk and safety, convenience of shopping facilities and frequency of rubbish collection.

Although most times implicit, there is very often a hierarchy of factors at play during choice processes. If this hierarchical order is understood, predicting how likely a person/people group would be to choose certain place is possible. However, if, with the purpose of eliciting the relative importance of each QoL indicator considered, residents were posed the question below, it is very likely that many of the attributes would be rated 'very important', which would not offer much help in understating these factors as indicators.

How important is _______ when you choose where to live?

– Air quality
– Safety
– Nearness to green spaces
– Etc

Hence, in order to overcome this limitation commonly found in preference elicitation procedures, Conjoint Analysis (CA) will be used, since it is a procedure that mimics real-life choice processes more accurately, and, through the data gathered can generate an efficient predictor tool so that expected changes emerging from scenarios can be tested on the effect on different "tribes" or life-stage groups in a given RUR or sub-division of a RUR (inner urban, outer urban, suburb, urban fringe, rural, remote rural etc). Furthermore, due to its robustness, it does not require a very large sample and allows choices to be examined per different groups (segments).

Conjoint Analysis is actually not a single method but a family of methods made popular in marketing research but with wider application to other fields of enquiry. It is based on the trade-offs people are prepared to make among attributes of the object of choice. As its most useful output, CA offers the possibility of generating a predictor tool for choice among hypothetical scenarios based on the given attributes, the "market simulator". This tool shows likelihood of choice according to different scenarios, with the possibility of segmentation of respondents according to characteristics of interest to each study. For the data collected in key areas as part of PLUREL (cast study regions and other areas) the market simulator will provide a valuable tool for local decision makers who will be able to test the effect on potential land use changes in their area on the population.

Among the types of CA available, Adaptive Conjoint Analysis (ACA) was chosen for the present study, as it provides a more respondent-friendly interview process and accommodates a greater number of attributes than the other CA types. The term "adaptive" refers to the fact that the computer administered interview is customized for each respondent; at each step, previous answers being used to decide which question to ask next, in order to obtain the most information about the respondent's preferences (Sawtooth Software, 2007)

The ACA study is based on:

1 The definition of the attributes of interest to the study, based on the project interests and existing literature;
2 The determination of mutually exclusive and relevant levels of each attribute (choice possibilities within each attribute);
3 The determination of the segments (groups of interest) within the study sample and
4 The design of a set of questions to allow grouping respondents into the desired segments.

For the definition of attributes and levels, it is necessary that they are of immediate relevance for respondents. Where quality of life is concerned, the technical indicators used to measure each aspect make no real sense to most people (see earlier explanation of environmental and social indicators). As an example, parts-per-million of certain elements or compounds in the air and levels of chemicals or micro-organisms in water supplies would mean very little to residents when choosing where to live. Hence, in order to gauge their relative importance through an ACA interview, these indicators are translated into terms respondents can relate to, i.e., the terms and categories respondents themselves would use when assessing their residential environment. Two of these are exemplified below.

Nature and green space	Presented in the literature as:	
	Green space as percentage of total land area (green space may include protected and unprotected natural areas, parks, vacant land with greenspace value, agricultural land, forest land, parks, gardens, allotments, cemeteries, river and lake shores etc)	
Urban air quality	Presented in the literature as:	
	Ambient levels and exceedances for ground-level ozone, PM10, CO, NO, SO2, benzene	

For the purpose of ACA could be translated as:

Public access to green spaces	• Access to green spaces requires a short walk • Access to green spaces requires a long walk • Access to green spaces requires transport
Urban air quality	• Air quality is excellent • Air quality is fair • Air quality is poor

Also useful for the purpose of this study is the concept of *affordances*, which originates in environmental psychology, having started with James J. Gibson (Gibson 1966, 1976, 1979). In his own words, "affordance of anything is a specific combination of the properties of its substance and its surfaces taken with reference to an animal" (Gibson, 1977:67). An affordance is a transactional construct, as it refers to the environment and to the person, as something between them. So when examining residential preference and choice, living in Place _, characterised by indicators X, Y and Z affords individuals A and B different things – leading to a different quality of life.

Adaptive Conjoint Analysis can help to measure accurately the perceived importance of quality of life indicators and to incorporate them into the impact assessment process by allowing researchers to map out the perceived quality of hypothetical living environments resulting from forecasted land-use scenarios. For example, ACA will make it possible to examine how people's preferences and perceived affordances relating to land use are affected by membership of different groups and segments in the population, such as older people and groups of immigrants.

Synoptic aggregation of indicator groups

The output of the indicator system is planned to be used to improve the background information for decision makers. Therefore, the diverse information about urban-rural interrelations has to be condensed into an overall evaluation scheme. This tool should consist of a minimum number of key indicators on the one hand and represent a maximum of significant information on the other. In Figure 7 a proposal for a graphical representation of the synoptic aggregation is sketched. It shows the outcomes of specific scenario conditions or driver combinations on land use structure and function (e.g. urban metabolism), landscape (ecosystem) integrity, ecosystem services, and socio-economic items, also referring to quality of life features. Although these figures seem to be rather complicated, a similar approach has successfully been used as a management tool in land use research in Northern Europe (Forbes et al. 2006).

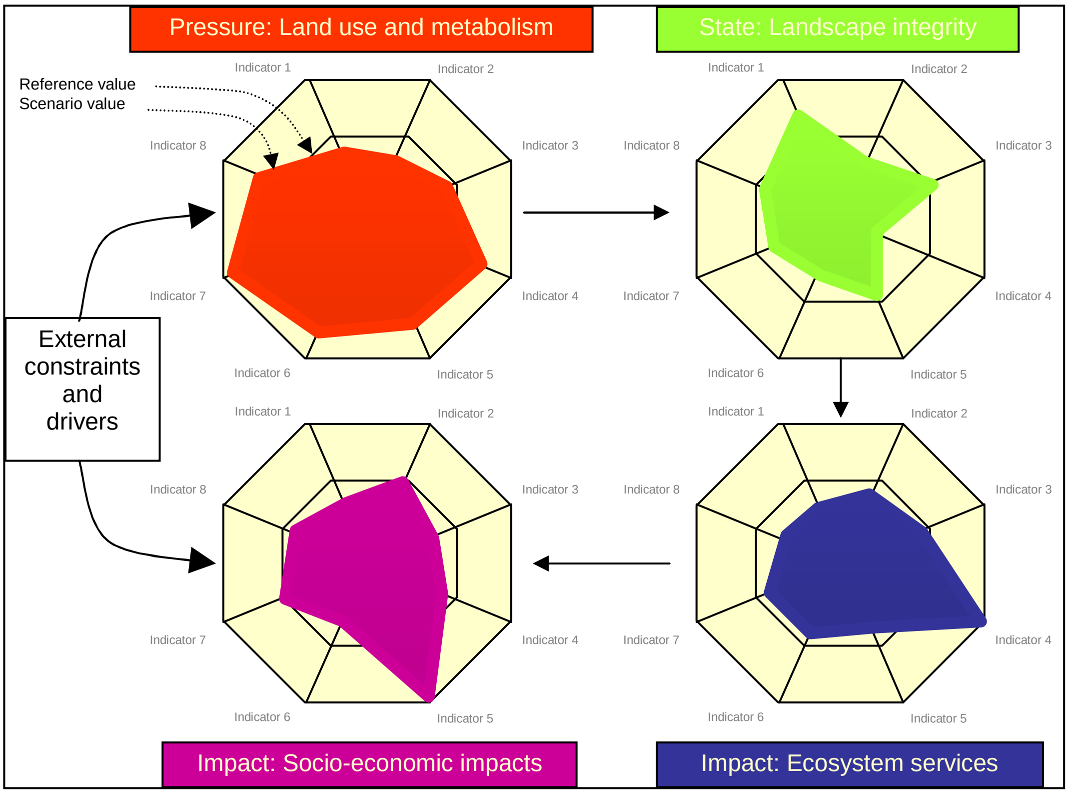

Figure 7: Outline of a synoptic presentation of key indicators

3. Procedural Steps of Indicator Development

Indicator development has turned out to be a continuous process with a steady demand for trade-offs between the theoretical requirements, the consequences of the basic conceptual model, the preferences of the users, the suitability into the project environment, feed backs with modelling items and data availability (see Figure 8). Thus, several feed backs, discussions, workshops and evaluations have been necessary to reach the recent state of the indicator set. Several sessions on indicators have been carried throughout the PLUREL conferences (e.g. indicator workshops in Leipzig, Warsaw, The Hague, Koper, plenum discussions in Leipzig and the Hague), and the indicator task force has provided a basic model as well as a basic variable set. During these processes the number of indicators has been decreased extremely in a stepwise manner, reflecting the multiple demands and constraints of the project groups. Due to the special PLUREL objectives - the analysis and management of *urban-rural interrelations* - many of the existing, approaches and literature proposals (e.g. Eurostat Sustainable Development Indicators, several sets of Sustainability Indicators, Indicators of the Federal Statistical Office Germany, EU Impact Assessment Items, “Core Framework Indicators”, “Sensor” and SIAT indicators, “Seamless” Indicators, Urban Indicators Guidelines from the UN Human Settlemts Programme, Eurostat Urban Audit Indicators, etc.) could not be used directly, but new constellations have been necessary. In the following passages some of the steps of indicator development will be sketched.

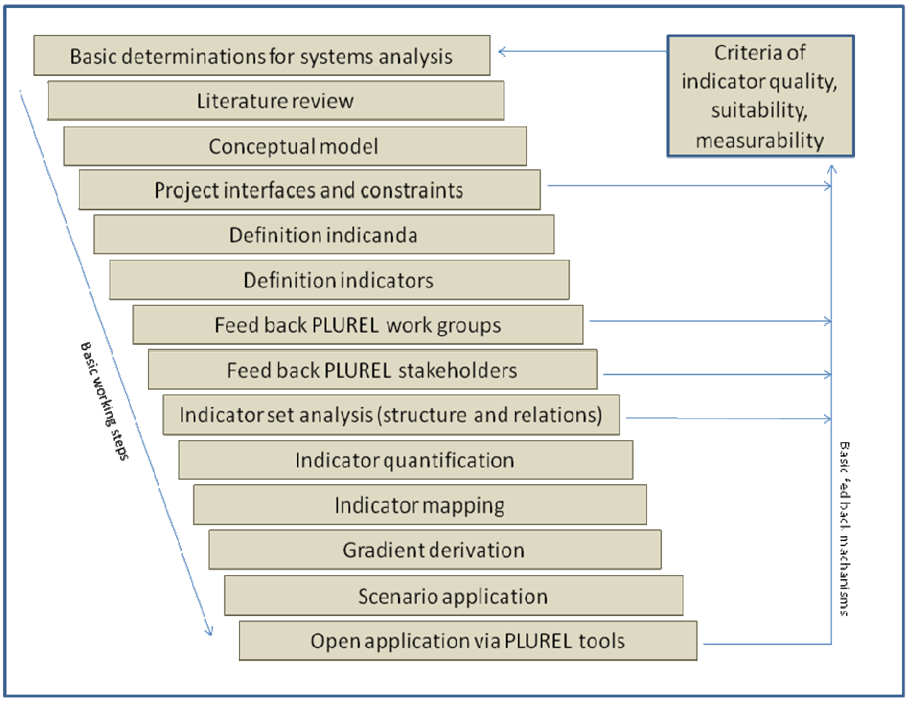

Figure 8: General steps of indicator development

3.1 Conceptual Indicator Model

The first preliminary PLUREL indicator list has been based on the *decision-focussed framework model* which has been discussed during the Warsaw Indicator Workshop (Figure 9). The framework model is based on the *DPSIR* approach of the EEA. In the inner part of the sketch the components of a decision process in an urban-rural region are arranged subsequently, describing the environmental and socio-economic consequences of a land use decision and providing criteria for the following decision process.

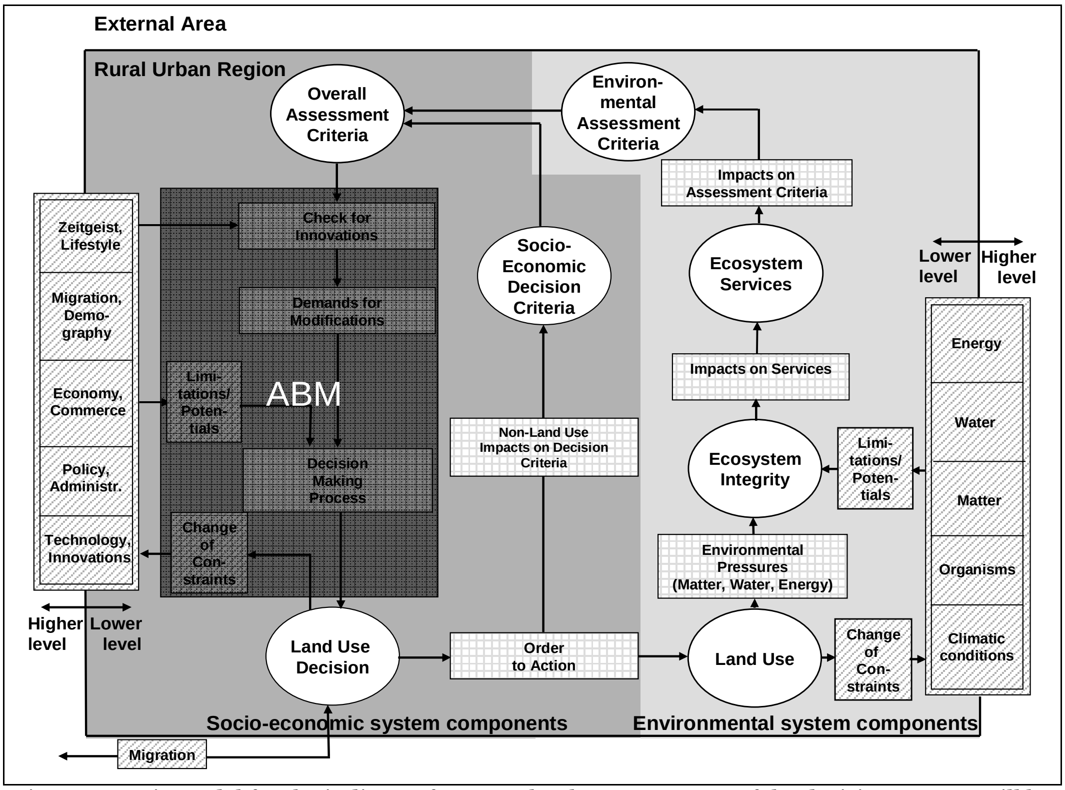

Figure 9: Basic model for the indicator framework. The components of the decision process will be investigated and exemplified by agent based models in M4.

All components are influenced by *constraints* from and exchanges (import, exports) with the external environment. At the left hand side social, technological and political constraints as well as broad-scale demographic processes are placed, while the environmental constraints and exchange processes can be found on the right hand side, directly influencing the landscape state variables, which are represented by ecosystem integrity.

The initial stage of the "decision cycle" refers to a certain *land use decision*, which changes the land use structure and which additionally provides modifications on a functional level, influencing the dynamics of ecological processes (e.g. water, energy, matter flows). The related *pressures* modify the environmental state of the system, which is aggregated to an indication of ecosystem (and landscape) *integrity*.

Due to that change, also the *ecosystem services* of the studied area are modified, providing a change of environmental decision criteria (assessment variables). The above described concept of ecosystem services combines the human with the ecological system by examining ecosystems from an anthropocentric perspective. Hence, ecosystem services can be used as a connector or translator between both systems. Therefore they are used here to link the ecosystem state with the decision making process. Additionally to the effect chain from land use change to impacts on ecosystem services, there are also effects which are not directly related to land use. These items also influence the follow-up decision. Thus, there is a sum of variable values which has been entitled *"overall assessment criteria"*. These arguments are used to find a new decision, by checking the state of the external constraints and by modifying the motivation of the decision making entities. In the end, the subsequent *decision* is made, and the circle can start again. The key components of this model have been translated into key issues in the respective list of indicators.

The resulting variable sets (see Table 6 for an overview of aspired indicanda) have had strong integrative characteristics in all steps of development. E.g. most of the EU *assessment criteria* (European Commission, 2005) as well as the *SENSOR land use* *functions* (SENSOR-IP, 2006) are included, and the information necessary for the *ABM modelling* group in Module 4 has been taken into account.

3.2 Framework Adaptation

The derived indicator sets have been modified several times, i.e. as a result of discussions in the project group and due to demands from the PLUREL stakeholder group. Besides the results of general discussions in several PLUREL project groups, there have been significant items influencing the structure of the indicator set, e.g.:

- conceptual restrictions to land use change based impacts (conceptual demand: restrict the indication to those impacts which are forced by land use changes only; therefore e.g. several pressures and several economic interrelations have not been taken into consideration)
- thematic restrictions towards RUR interrelationships (conceptual demand: focus on the gradients and processes in the rural-urban gradient; therefore the indicator set is not directed towards an isolated description of urban or rural qualities; the spatial interrelations play a major role)
- development and usage of new indicator calculation algorithms
- conceptual changes in the overall project outline with conceptual consequences due to financial restrictions for the indicator work package
- conceptual changes referring to the scenario outputs in M1 and the introduction of MOLAND as a focal M4 modelling tool
- adaptations due to the dynamics concerning the modelling demands and the ABM modelling outputs
- adaptations as results from the application of conjoint analyses, i.e. referring to social indicators leading to temporal decoupling (and a delay in presenting the respective results)
- indicator aggregations and development of composite indicators
- adaptations with reference to the interrelation analysis (response functions, simulation models, indicator matrix)
- data availabilities provoking restrictions for the realization of the original framework

Besides these past dynamics, there will be also a development of the indicator system in the future, i.e. concerning the results of the social analyses and their consequences for the indicator set) and the factual introduction of economic indicators, which will occur with a delay due to changes in the work package responsibilities.

Table 6: Basic structure of the indicator framework as a result of the indicator-task-force discussions in 2007 and 2008 (no indicators included due to their high number)

System component	Key question	Key issues (Indicanda)
Socio-economic and environmental external constraints ➔ driver	Which external inputs and constraints do affect the decision making process that leads to land use changes in the RUR?	Lifestyle Migration Economy, Commerce Policy, Administration Technology Climate
Land use structure ➔ pressure	What are the important land cover units and how are they spatially distributed?	Agricultural areas Forest areas Semi-natural areas Artificial surfaces
Land use function and RUR metabolism ➔ pressure	Which are the land use-based processes that are resulting from land use pattern and intensity?	Energy flows Water flows Matter flows Material flows
Ecosystem integrity ➔ state	Which components of ecosystem integrity (that	Nutrient cycling Water cycling

	guarantee the self-organizing capacity of ecosystems) are affected by environmental pressures?	Carbon cycling Energy budgets Biodiversity
Ecosystem services ➔ impact	Which ecosystem services are affected by a change of ecosystem structure and functioning?	Provisioning services Regulation services Cultural services
Socio-economic assessment criteria ➔ impact	Which are the socio-economic criteria and consequences of a land use change decision?	Economic performance Social and health infrastructure Transport Demography security
Decision process ➔ Response ➔ Driver	The decision is both a response of the ecological, social and economic conditions as well as the driver for new land use changes.	The decision process is not indicated (because the indicators provide the information for this process) but partly simulated, e.g. in the models of AMB land

3.3 Stakeholder Feedback

A major input for adaptation of course has been arising from the discussions with the PLUREL stakeholder group. The following chapter summarises the votes of Stakeholders for the indicators in form of diagrams and tables and thereby gives an overview about their preferences. The first figure shows the overall distribution of the 115 votes on the main components of the indicator system (Driver, Pressure, State and Impact indicators). With help of the second to sixth figure, the distribution of votes for each indicator framework component is shown in more detail. In order to retain the clearness of the figures, only the indicanda are illustrated. To explore the preferences for single indicators, a list of the most important indicators from the stakeholders' points of view is provided subsequently. This list includes the six favoured indicators from each framework component and the number of votes given for these indicators.

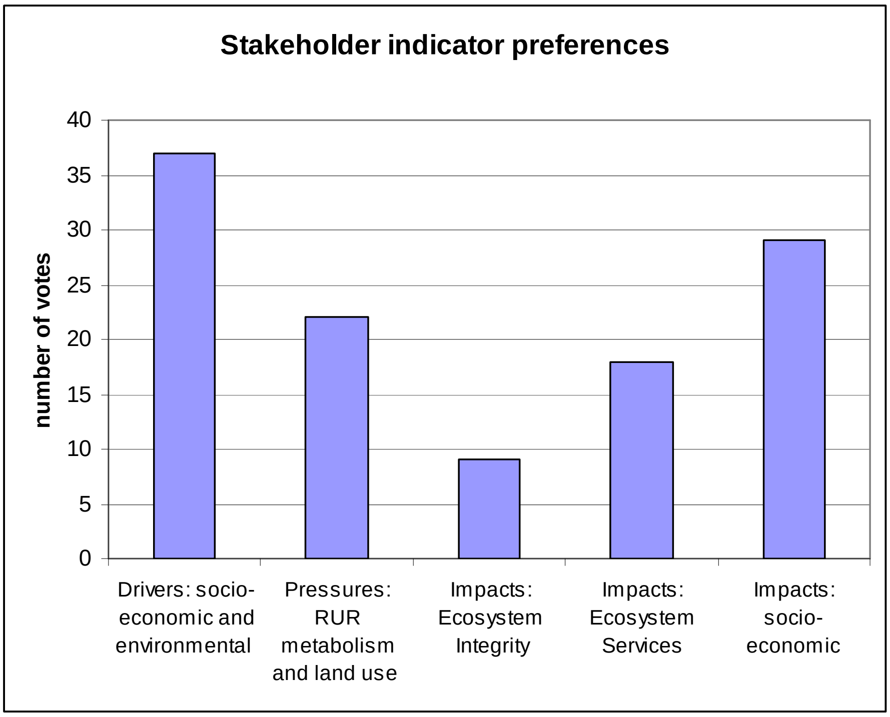

Figure 10: Distribution of stakeholder votes on Driver, Pressure and Impact Indicators

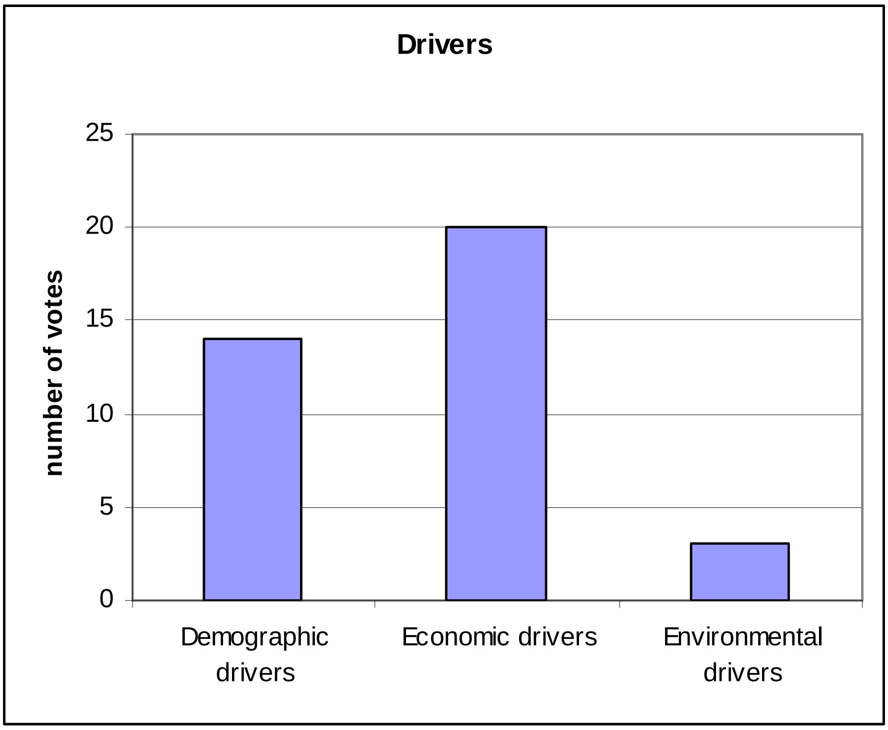

Figure 11: Distribution of stakeholder votes on demographic, economic and environmental driver indicators

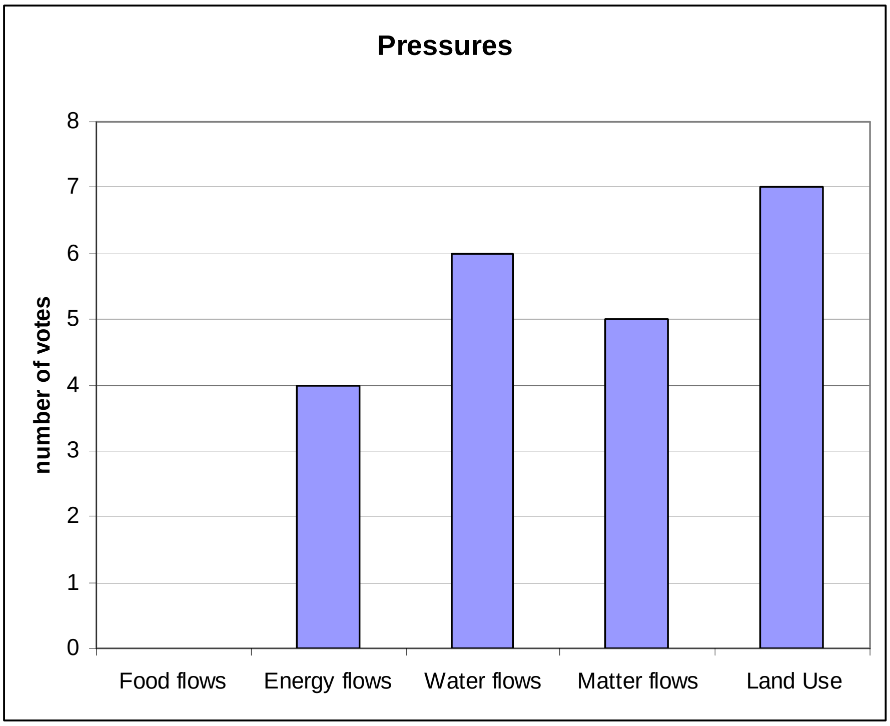

Figure 12: Distribution of stakeholder votes on pressure indicators (urban metabolism and land use)

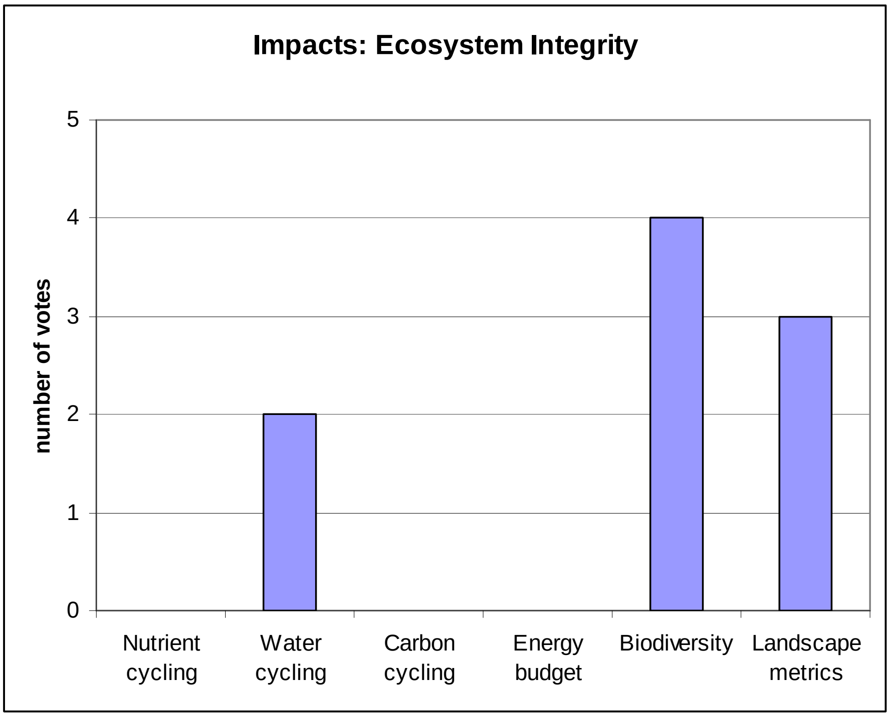

Figure 13: Distribution of stakeholder votes on ecosystem integrity indicators

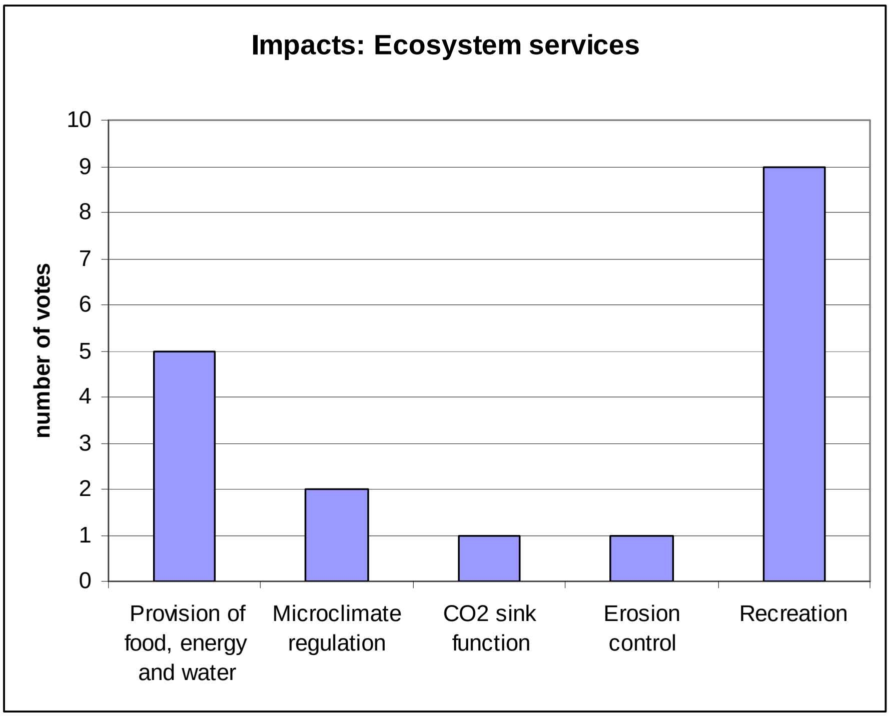

Figure 14: Distribution of stakeholder votes on ecosystem services indicators

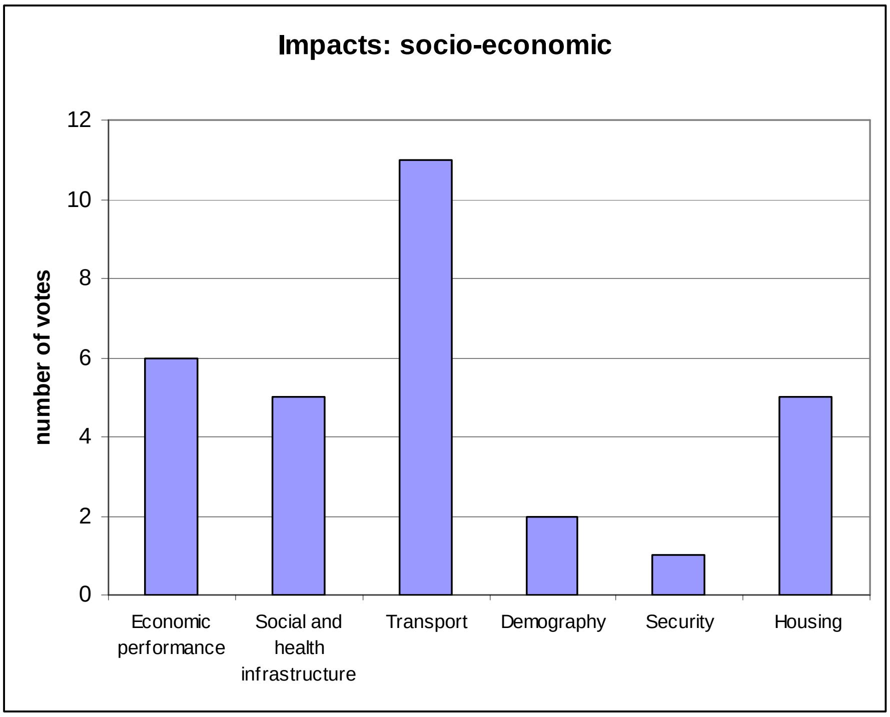

Figure 15: Distribution of stakeholder votes on socio-economic impact indicators

When exploring the stakeholders' indicator preferences, it becomes clear that land use related socio-economic issues are given a much bigger importance than environmental issues. Firstly, this can be seen in Figure 10 which shows the overall distribution of votes on the different framework components. The environment related components of ecosystem integrity and ecosystem services received far less votes than the socio-economic related components of driver and impact indicators. Also the second figure proves this fact, as the economic and demographic drivers of land use changes are assessed to be of much greater importance than the environmental ones. The ecosystem integrity indicators, apart from issues related to biodiversity, have little importance for Stakeholders. Recreation, as a cultural ecosystem service, is the by far the most valued ecosystem service, followed by the provisioning service food production. Regulation services on the other hand have little importance for Stakeholders. Among the socio-economic impact indicators, transport issues are by far the most important valued indicators, followed by economic performance and housing issues.

Table 7: The Top 6 indicators of driver, pressure, state and impact variables from the stakeholders' points of view

Top 6 Driver Indicators	**Top 6 Pressure Indicators**
• Employment per sector (6 votes) • GDP per capita (5 votes) • Population growth rate (5 votes) • Unemployment rate (3 votes) • Value added per sector (3 votes) • Subsidies (3 votes)	• Urban Sprawl (6 votes) • CO_2 emissions (5 votes) • Energy consumption (4 votes) • Water consumption (2 votes) • Water extraction rate (2 votes) • Treated Sewage (2 votes)
Top 6 State Indicators Ecosystem Integrity	**Top 6 Impact Indicators Ecosystem Services**
• Habitat type (4 votes) • Surface runoff (2 votes) • Evapotranspiration (1 vote) • Mean patch size (1 vote) • Patch density (1 vote) • Edge density (1 vote)	• Accessibility of green space and water area (9 votes) • Food production (4 votes) • Groundwater recharge (1 vote) • Land surface temperature (1 vote) • Carbon sequestration (1 vote) • Soil loss (1 vote)
Top 6 Impact Indicators Socio-economic issues	
• Average time of journey to work (4 votes) • Price per m^2 land (4 votes) • Access to public transport (3 votes) • Transport network density (3 votes) • Housing area per person (3 votes) • Population density (2 votes)	

3.4 Indicator relations and quantification

In a next step the selected indicators have been checked due to the quality criteria in Tables 1 and 2, and in context with an additional task an in analysis of the interrelations between the indicators was carried out to identify the conceptual importance of the single variables, to establish hypotheses on the interactions within the system and to better understand the functional schemes of rural-urban regions.

Analyzing the relations between the indicators (indicator matrix)

When choosing the key indicators to be used in the indicator matrix, we tried to consider the Stakeholder preferences as much as possible. Therefore, we included the Top 4 valued indicators by Stakeholders of each framework component into the key indicator list for the matrix. However, this was not possible concerning to the socio-economic impact indicators, because three transport related indicators have been among the top 4 valued indicators. To avoid redundancies, we proposed only two of them. We also put greater emphasis on ecosystem integrity and ecosystem service indicators than the Stakeholders, because we think that these are indispensable components in the whole framework model. Functioning ecosystems, in other words high ecosystem integrity values, are the basic prerequisite to guarantee the capacity of ecosystems to provide ecosystem goods and services, which in turn has an important impact on human well being (Millennium Ecosystem Assessment, 2005). Therefore, it is absolutely necessary to include several integrity indicators within the indicator matrix.

In Table 8, the chosen key indicators for the matrix operations are highlighted in red in the current indicator list. Figure 16 summarizes the utilized key indicators in four diagrams, one for each framework component. Socio-economic driver and impact indicators are summarized in one diagram, as these indicators are at the same time impacts of a land use change and drivers for the next land use changing decision.

Table 8: Key Indicators as part of the indicator list as result of the indicator task force discussions in 2008

System Components		Key Issues	Exemplary Indicators
Socio-economic and environ-mental constraints **Driver**	Which important external inputs and which constraints do affect the decision making process in the RUR?	**Demographic drivers**	**Population growth rate** Fertility rate **Mean age** **Females / males** Range of labour migration (national and international) Range of pensioners migration (national and international) International inward migration Migration crossing EU borders
		Economic drivers	Consumer price index **GDP per capita** Value added by sector (Nemesis outputs for agriculture, forestry, urbanisation, transport- energy infrastructures, tourism, nature protection, land prices) **Employment per sector** **Unemployment rate** Subsidies (e.g. for industry, agriculture)
		Environmental drivers climatic conditions	Air temperature Precipitation
		Environmental drivers water, energy and matter flows	Food/Biomass im- and exports Material im- and exports Energy im- and exports Water im- and exports
RUR metabolism and land use **Pressure**	Which are the land use-based processes that are resulting from land use pattern and intensity?	**Food flows**	**Food consumption per person**
		Energy flows	**Energy consumption per person** Energy consumption per sector
		Water flows	**Water consumption per person** Water extraction rate (ground and surface water) Treated sewage
		Material and matter flows	N and P from fertilizer and livestock (nutrient input) Pesticide consumption **Solid waste production per person** **Greenhouse gas emissions per ha** NOx emissions NH3 emissions CH4 emissions Particulate matter concentration
		Land Use	**Corine classes** Crop types **Urban sprawl** **Habitat fragmentation** **Transport network density** **Habitat type (% nature conservation area)**

Ecosystem Integrity **State**	Which components of ecosystem integrity (that guarantee the self-organizing capacity of ecosystems) are affected by environmental pressures?	**Nutrient cycling**	**Nutrient loss (N)** Nutrient budget (N)
		Water cycling	**Surface run-off** Infiltration **Percolation** **Evapotranspiration** Transpiration / Evapotranspiration (biotic water flow)
		Carbon cycling	**Respiration (CO_2)**
		Energy budget	**NPP (Primary production of biomass)** Metabolic efficiency (respiration per biomass)
		Biodiversity	**Breeding bird community**
		Heterogeneity	**Landscape heterogeneity**
Ecosystem Services **Impact**	Which ecosystem services are affected by a change of ecosystem structure and functioning?	**Provision of food, energy, and water resources**	**Food production** Wood production **Groundwater recharge**
		Microclimate regulation	**Land surface temperature**
		CO2 sink function	**Carbon sequestration (Soil organic carbon and C in phytomass (g/m^2))**
		Erosion control	**Soil loss**
		Recreation	**Accessibility of green space and water area**
Socio-economic assessment criteria **Impact**	Which are the socio-economic modifications resulting from a land use change?	**Economic performance**	Household income **Price per m^2 land**
		Social and health infrastructure	**Number of doctors / inhabitants** **Number of schools per 1000 children** Percentage of population without school graduation
		Transport	Access to public transport Number of commuters **Average time of journey to work**
		Demography	**Population density**
		Security	Level of recorded crime
		Housing	Noise –average decibel level Shopping facilities - accessibility and choice Waste collection (frequency) Average annual rent per m^2house or apartment **Average household size** **Housing area per person in m^2**

Methods and matrix concept

All chosen key indicators were included into the indicator matrix, with each indicator occurring one time on each axes. To save space, the indicator names were replaced by binary numbers, the first of them indicating the framework component (1: Pressure indicators, 2: Ecosystem integrity indicators, 3: Ecosystem service indicators, 4: Socio-economic impact and driver indicators, see figure 7). The first pressure indicator, the Corine Land Cover Classes, had to be further distinguished to consider each of the main land use classes separately:

1/1a: urban area
1/1b: industry, commerce and transport area
1/1c: urban green
1/1d: agricultural area
1/1e: forest and natural area
1/1f: water and wetlands

Also the first socio-economic indicator, the employment per sector, had to be subdivided:
4/1a: employment in first sector
4/1b: employment in second sector
4/1c: employment in third sector

All indicators were then checked concerning their mutual interaction and relevance using the two-dimensional matrix. In this matrix, the interrelations among the indicators were analysed (method based on Patten 1971, Kaul & Reins 2000) by considering the following three different types of interrelations. The types of interrelation discovered is symbolised with a d, i, or a blank field:

- direct relation d
- indirect relation i
- no relevant relation blank field

An additional distinction was made between positive or negative correlations. Positive correlations are symbolised by a red character, whereas negative correlations are symbolised by a blue character. If a direction of influence could not be identified, e.g. because both directions are possible or the hypotheses about the indicator relation found in literature are contradictory, the respective character is left black. An ambiguous direction of influence can be caused, among others, by different geographical situations of cities. For instance, urban green increases the evapotranspiration in cities and thereby reduces the urban heat island effect. The result is decreased energy consumption for air conditioning during the summer. In cold climates on the other hand, a reduced urban heat island can increase the energy consumption by increased heating. Another example is the relation between agricultural land and the carbon sequestration function. Agricultural land can be a source or a sink for carbon dioxide, depending on the crop and soil type, the soil temperature, the soil humidity and the management methods (Parkin et al. 2005). To demonstrate the feedback type, the following depictions were used:

- direct, positive relation d
- direct, negative relation d
- indirect, positive relation i
- indirect, negative relation: i
- direct relation that can be either positive or negative d
- indirect relation that can be i either positive or negative

A direct relation denotes that one indicator is directly affected by the other. Those are more quickly to discover than indirect relations or indirect effects in systems, because the latter tend to be more ambiguous (Burkhard, 2004; Fath and Patten 2000). To distinguish between direct and indirect relations it is assumed, that in an indirect relation one indicator A can only be correlated with indicator B by integration of at least yet another indicator C (Burkhard, 2004). To decide, if a land use change has a positive or negative effect on a change of ecosystem integrity or ecosystem services, it was always compared to a sealed surface. For instance, the effect of agricultural land on the amount of surface runoff was seen as negative, even if the surface runoff on agricultural land is still much higher than on forest or natural area. The indicators in the rows (on the ordinate) are seen as the “active” elements that are influencing the indicators in the columns. This is an important distinction, because the mutual influence of indicators is not the same in both directions, resulting in a non-symmetrical matrix. By counting the numbers of relations of the indicators (last row and column in the matrix) it was then possible to separate certain “key elements” that have the main effects on the whole system. The effects that one element has on the others are indicated by the number of active direct and indirect relations at the end of the columns. A higher value implies a stronger, a lower value a weaker effect on the system. The effects of all elements in the whole system on one certain variable are shown by the amount of passive direct and indirect relations in the last row of the matrix. A higher (respectively lower) amount of passive relations implies a stronger (respectively weaker) effect of the system on a certain variable (Burkhard, 2004; Kaul and Reins 2002).

To decide about the relationship of indicators, a literature review was conducted and some exemplary relations between indicators discussed in the literature are listed in the result part of this paper. However, it was not possible to give references for all indicator relations due to the enormous amount of interrelations.

Results of the matrix analysis

The results about direct and indirect relations between all indicators are presented in table 9, with red characters symbolizing positive correlations and blue characters symbolizing negative correlations. Figure 17 summarizes the interrelations found between the indicator framework components. The figure reveals that land use changes put a strong, mostly direct, pressure on ecosystem integrity, ecosystem services and socio-economic indicators. In comparison to that, the impact of ecosystem integrity and ecosystem services on the other system components is rather weak. The socio-economic indicators act much more as drivers for land use changes than being impacted by land use changes or changes of ecosystem services and integrity. Interactions that directly follow the DPSIR cycle show more direct than indirect relations, the others are mainly dominated by indirect relations.

As key active elements, we identified the land use class and urban sprawl indicators, the hydrology related integrity indicators, soil loss and surface temperature among the service indicators and population growth and density among the socio-economic indicators. As key passive elements, we identified energy and water consumption and greenhouse gas emissions among the pressure indicators, evapotranspiration and net primary production among the integrity indicators, carbon sequestration and groundwater recharge among the service indicators and price per land, population growth and density among the socio-economic indicators.

The matrix was used as guideline for further works: On the one hand the most significant relations and the subsequent most important elements (showing high degrees of interactions) have been included in the RUR gradient system of WP 4.3. On the other hand, the significance of interrelations will guide the derivation of response functions on the regional level. A first step is the definition of respective hypotheses, reaching from the state of word models over transfer rules and statistical descriptions (e.g. regressions, classifications …) up to parts of simulation models. These works will be carried out in cooperation with Module 2 to adapt and accomplish response functions on different PLUREL scales. To illustrate the first step of this work, table 10 contains exemplary hypotheses about indicator relationships from literature.

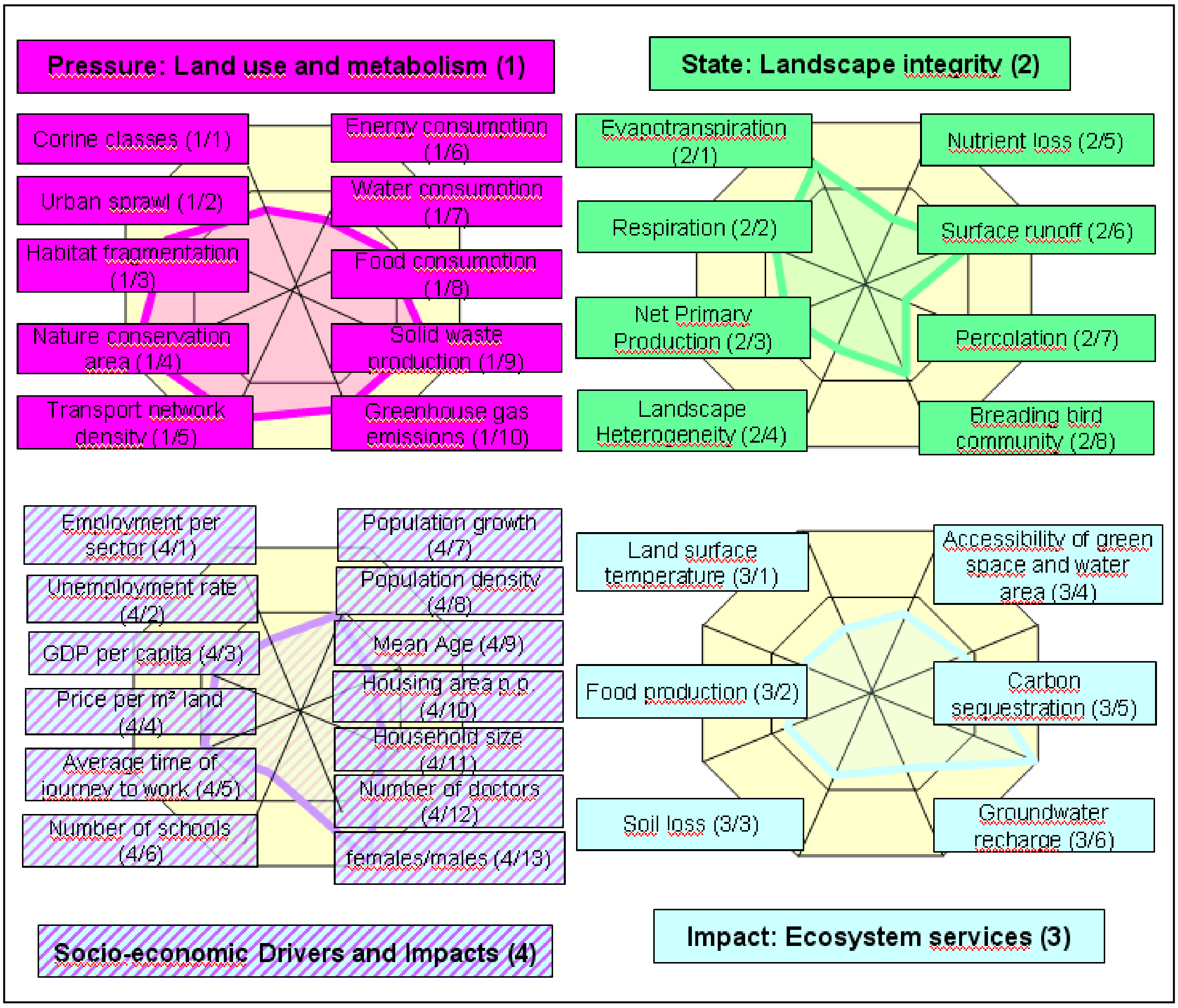

Figure 16: Driver, Pressure, State and Impact Indicators used in the indicator matrix

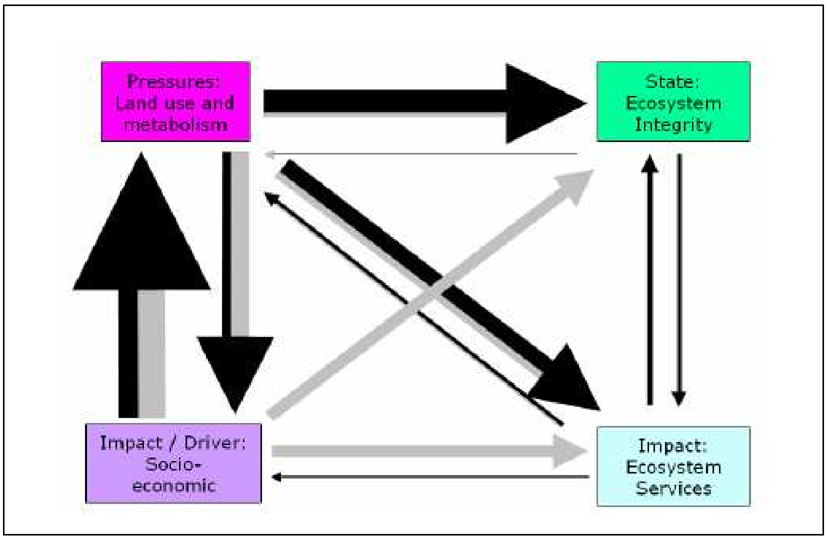

Figure 17: Interrelationships between indicator framework components as found in the indicator matrix. The width of the arrows is reflecting the number of relations, the grey part of the arrows the significance of indirect relations.

Table 9: Interrelation matrix between the selected indicators

		Pressures: land use and rur-metabolism															State: Integrity								Impacts: ES Services						Impacts and Drivers: socio-economic															∑ d	∑ i
		1a	1b	1c	1d	1e	1f	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	1	2	3	4	5	6	1a	1b	1c	2	3	4	5	6	7	8	9	10	11	12	13		
Pressures: land use and rur-metabolism	1a	-	d	d	d	d	d	d	d	d	d	i	i	i	i	i	d	d	d	d		d	d	d	d	i	d	d	d	d	i	i	d	i	i	d		i	d	d	i	i	i	i	i	25	16
	1b	d	-	d	d	d	d	d	d	d	d	i	i		i	i	d	d	d	d		d	d	d	d	i	d	d	d	d	i	d	d	i	i	d	d		d	d	i	i	i			27	11
	1c			-	i	i	d		d	d	d	d	d				d	d	d	d	d	d	d	d	d		d	d	d	d						d				i						20	3
	1d	d	d	i	-	d	d	d	i	i	d	i	d			d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	i	i	i	i	d		i	i	i	i	i	i	i	i	24	17
	1e				d	-	i		d	d	d	i	i			i	d	d	d	d	d	d	d	d	d	i	d	d	d	d	d	i	i	i	i	d		i	i	i	i	i	i	i	i	19	17
	1f	d	d	d	d	d	-	d	d	d	d	i	i			i	d	d	d	d	d	d	d	d	d	i		d	d	d	i	i	i	i	i	d										22	9
	2	d	d	d	d	d	d	-	d	i	d	d	d			i	d	d	d	d		d	d	d	d	i	d	i	d	d							d			d		d	d			25	4
	3								-								i	i	i	i		i	i	d			i		i	i																1	9
	4	d	d	d	i	d	d	i	d	-	d					i	d	d	d	d	d	d	d	d	d	i	d	d	d	d	i	i	i													20	7
	5	d	d	d	d	d	d	d	d	i	-	i				i	i	i	i	i		i	i	i	i	i	i	d	i	i						d	d		i	i						11	17
	6				d	i	i			i		-				d									d	i																				3	4
	7						i					d	-			i																														1	2
	8				d	i	i					d	d	-	d	i										d	d	i	i	i																6	6
	9											d	d		-	d																														3	0
	10											i				-			i						i	i																				0	4
State: Integrity	1											i				i	-				i	d	d		d		i			d																4	4
	2															d	d	-	d						i	i			i																	3	3
	3																d	d	-		d					d			d																	5	0
	4																			-				d																						1	0
	5																		d		-					i																				1	1
	6																d				d	-	d		i		d			d																5	1
	7																d	i	d		d	d	-				i			d																5	2
	8																							-																						0	0
Impact: ES Services	1											d	d			i	d	d	d			d	d		-	i			i										i							7	3
	2				i	i	i					d	d		d	d		d			d					-	i		d	i																7	5
	3				d													d	d	d	d	d	d	i		d	-		d	i	i					d										10	3
	4											i				i												-								d			d		d					3	2
	5																		d						i	i			-																	1	2
	6						d										d		d								i			-																3	1

		Pressures: land use and rur-metabolism															State: Integrity								Impacts: ES Services						Impacts and Drivers: socio-economic															∑ d	∑ i
		1a	1b	1c	1d	1e	1f	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	1	2	3	4	5	6	1a	1b	1c	2	3	4	5	6	7	8	9	10	11	12	13		
Impacts and Drivers: socio-economic	1a	i	i	i	i	i	i	i	i	i	i	i	i		i	i	i		i		i	i	i	i	i	i	i	i	i	i	-	i	i	i	i	i	i	i	i	i	i	i	i	i	i	0	40
	1b	i	i	i	i	i	i	i	i	i	i	i	i		i	i	i		i			i	i	i	i	i	i	i	i	i	i	-	i	i	i	i			i	i	i	i	i	i	i	0	37
	1c	i	i	i	i	i	i	i	i	i	i	i	i	i	i	i	i		i			i	i	i	i	i	i	i	i	i	i	i	-	i	i	i			i	i	i	i	i	i	i	0	37
	2			i				i	i			i	i	i	i	i								i							i			-	d	i			d	d	i	d	d	i	i	5	14
	3	i	i	i	i	i	i	d	i	i	i	d	d	d	d	d								i										d	-	d			d	d	i	d	d	d	i	13	12
	4	d	d	d	d	d	d	d	d	d	d	i	i			i															d	d	d			-				d	i	d	d	i		16	5
	5		i					i	i	i	d	d				d	i					i	i	i	i		i			i							-	i	i	i	i	i	i	i		3	18
	6																																i	i	i			-	d	d	d	i	d			4	4
	7	d	d	d	d	d	d	d	i	i	d	d	d			d	i		i			i	i	i	i	i	i	i	i	i						d	d	d	-	d	d	d	d	d	d	20	13
	8	d	d	d	d	d	d	d	i	i	d	d	d			d	i		i			i	i	i	i	i	i	i	i	i						d	d	d		-	d	d	d	d	d	19	13
	9										i	i	i			i																				i		d	d		-	d	d	d	d	6	5
	10	i	i		i	i	i	d	i			d	d		d	d	i					i	i																	d		-				6	9
	11							d				d	d	d	d	d																										d	-			7	0
	12																																						d		d			-		2	0
	13													d																			d					i	d		d				-	4	1
∑d		9	9	9	12	10	11	11	9	6	12	13	12	3	5	11	14	12	15	9	10	12	12	10	10	4	9	8	11	11	3	2	4	1	1	12	5	3	9	9	6	8	8	4	3		
∑i		5	6	6	8	9	10	6	10	11	5	15	10	3	6	18	9	3	8	2	2	9	9	10	11	18	12	7	10	11	8	7	7	9	9	5	1	6	8	8	9	9	8	8	8		

Table 10: Exemplary hypotheses about indicator relationships from literature

Basic statements about indicator relationships	Literature source
Population size and **age structure** have clear effects on **energy consumption**	York (2007)
Economic growth is likely to lead in an increase in **energy consumption**	York (2007)
Population size and **economic development** are key driving forces of **carbon dioxide emissions**	York (2007)
Older populations tend to have smaller **household sizes** and more consumers of energy intensive products, such as cars.	York (2007)
An increase in the proportion of the **population that is older than 65** corresponds with an increase in **energy consumption**	York (2007)
Urbanisation has a positive effect on **energy consumption**	York (2007)
CO2 level and **temperatures** have an impact on the **food production**	Ayensu et al. (1999)
Higher **Food production** leads to higher **nutrient loss** and **CH4** and **N2O** emissions to the atmosphere, a higher **water demand**, decrease of **forest area** and more **erosion** and **surface runoff**	Ayensu et al. (1999)
Bird diversity decreases with **urbanisation**	Clergeau et al. (1998)
Spatial heterogeneity and density of woody patches predicts both **species richness** and Shannon Diversity	Blair (2004)
Wealthier neighbourhoods (higher **GDP)** have more **native bird species**	Melles (2005)
Increase of plant and **bird numbers** with economic **income**	Kinzig et al. (2005)
The higher the **population density**, the lower the **per capita transport energy**	Kennedy et el. (2007)
Urban expansion leads to an increasing amount of soil sealing that heavily affects the natural **water cycle**, modifies **energy flows** and **nutrient cycles**	McDonnell and Pickett (1990) McDonnell et al. (1997) Vitousek et al. (1997)
Sprawled cities can provide **more urban ecosystem services** and support the environmental quality in cities but they are supposed to **consume more energy** and occupy a larger amount of land	Bolund and Hunhammar (1999)
The water cycle is changed through the **sealing of soils.** This leads to a lower **groundwater recharge**, higher **surface run-off** and lower **evapotranspiration.**	Pickett et al. (2001) Wessolek (2008)
The uptake of NO_3^- and NH_4^+ by plants in rural areas is often not in balance with the high input of fertilizer on **agricultural areas**, leading to **nitrate leaching** and NH_3 emissions to the atmosphere.	Odum (1987)

The **micro climate regulation** that helps reduce the urban heat island effect is provided by all natural ecosystems in urban areas, as **urban green** increases **evapotranspiration** and therefore has a cooling effect.	Bolund and Hunhammar (1999)
Population growth leads to a growth of **urban area**, population shrinkage does not provoke a stop or decrease of urban development	EEA (2006)
An increasing **housing area per person,** a decreasing **household size** can be seen as reasons (among others) for **urban sprawl**	EEA (2006)
An increasing **unemployment rate** leads in a **population shrinkage** due to emigration	Büttner (2006)
In some rural regions in Germany with a low **population density** and a **shrinking population**, the **number of doctors** is too low to guarantee a sufficient health care	Schmidt (2006) Kocks (2007)
An **ageing population** leads to an increasing number of **single households**	Waltersbacher (2007)
The **ageing population** and a higher **income** leads to a higher **housing area per person**	Waltersbacher (2007)
A positive **economic development** is followed by **immigration** of people and enterprises and therefore leads to a higher demand for **housing, traffic and industry and commerce area**	Schmidt and Große Starmann (2007)
Soil respiration depends on **temperature, soil water content,** organic matter, soil texture and plant root activity	Parkin et al.
Correlation between **land use classes** and **integrity** indicators	Burkhard (2004)
Total volume of **solid waste** does not show necessarily a relation with the total **population growth** or shrinkage, but depends on legal restrictions, waste collection systems and economic incentives	Heiland et al (2005)
Energy consumption per person increases with a **shrinking population** because of a more inefficient use	Heiland et al (2005)
Population shrinkage can lead to a better microclimatic condition (**lower land surface temperatures**) when it comes along with perforation and deconstruction of houses	Heiland et al (2005)
The decrease of **agricultural area** is mainly caused by growing **settlement area**	Waldharft et al (2000)
A **shrinking population** can lead to perforation and deconstruction of houses and an **increase of urban green**	BBR (2004)

Discussion of the matrix outcome

First of all, it must be clear that the results of the indicator matrix are reflecting the personal knowledge and assumptions of the authors. Not all of the almost 2000 indicator relations could be proved by literature studies, partly because suitable studies do not exist so far, partly because of the enormous time intensity of this task. Nevertheless, even if some detailed relations are arguable and still to be investigated, the basic results of the matrix shown in figure 17 are supposed to be reproducible by every author familiar with the subject in question.

These results are revealing interesting facts about the inner-system relationships: By studying the indicators and the resulting relations between the system components, it becomes obvious that the thickness of arrows reflecting the strength of interrelations in figure 17, strongly depends on the choice of indicators to represent each system component. For instance, the impact of ecosystem service indicators on socio-economic indicators are weak, because no environmental related quality of life indicators, such as noise level or clean drinking water availability, have been included into the analysis. They seemed to have little or no relevance for Stakeholders in comparison to economic and transport related issues. The results of the Conjoint Analysis in Milestone 4.3.10 will reveal further details about the question which socio-economic and environment related quality of life indicators really matter for peoples' decisions. Ironically, the relation between ecosystem service indicators and socio-economic indicators will be the stronger, the poorer the quality of the environment is. In European rural-urban regions with a rather high environmental standard, an assured provision of clean drinking water, regular waste collection, a secure food supply etc., non-environment related socio-economic issues may be given a greater attention. However, our dependency on the functioning of ecosystems and the impact of processes going on in European rural-urban regions on the global environment should not be ignored and in spite of the inherent self evidence of service provisions, their contributions to human well-being are existing and most significant.

Another interesting result of the matrix is the fact that the urban metabolism indicators as part of the pressure component, do not show a considerable impact on ecosystem integrity and ecosystem service indicators, but they are themselves influenced by several socio-economic issues and therefore the passive key elements among the pressure indicators. This does not mean that a change in the urban metabolism has little effects on ecosystems in general, but it merely has little effects on the local and regional level, as global urban relations nowadays often are stronger than rural urban relations. Food, water and energy can be imported from far away, as well as solid and liquid wastes can be exported outside the rural urban region. Also the emissions of greenhouse gases have a global, rather than a regional impact. Nevertheless, the urban metabolism is strongly influenced by decisions and processes operating on inside the rural urban region, showing that metabolism indicators are an important part of our indicator system when considering our responsibility for the global environment.

The matrix also reveals the active and passive key elements which have the most impact or are the most impacted by other system elements. It is not surprising that land use classes and the population number and density are the most important key elements. On the other hand, the matrix also shows which elements interact very little with the others, among these are the number of doctors and the food consumption. As they seem to have little influence, their inclusion to the key indicators has to be discussed in the upcoming indicator task force meetings. Also in this case, the results might show that we are living in a luxury situation. But to guarantee social and environmental security, also these items have a high general significance.

Summarizing, the matrix analysis has provided an interesting viewpoint on the selected indicators. The significance and strength of the found relations was used as another argument for the definition of a key indicator set for structural and functional RUR-gradients. The resulting set of variables can be found in the following chapter.

Indicator quantification

The indicator quantification has been generally carried out on the base of the described concentric cycles around the city centers of the case study areas. The land cover data and other parameters have been digitized and transformed into GIS data sets. The respective quantification procedures, which will be sketched for each tested indicator in the following sections, were carried out within these data sets. Besides transformation rules and response functions, models were used for this purpose as well as comprehensive applications of official statistics. The results were furthermore transformed into rural-urban gradients which can be used to depict the potential of exchange processes between cities and their hinterlands.

The quantification of most social indicators is based on an analysis of the Quality of Life in rural-urban regions applied to selected case studies. The output of these investigations will be in form of a questionnaire and results for the case studies, integrated into a preference simulator. Currently, empirical studies to feed the social indicators are carried out using the method of an Adaptive Conjoint Analysis. One of the results of this analysis will be a distinction of indicator significance for housing decisions. These parameters will be integrated into the indicator system. The calculation of most of the economic indicators will be related to a determination of costs related to carbon stocks, air pollution and green spaces.

The organizational responsibilities for the different indicator groups are documented in Box 1.

4. Key Indicators for Rural-Urban Interrelations

In the following chapter the focal selected indicators are described. After an overview in form of a variable list, there are exemplary descriptions of ecological indicators referring to ecological integrity and ecosystem services, followed by social and economic indicators. The tested indicators are illustrated by examples of their quantification results including their spatial distributions.

4.1 Overview of Suggested Key Indicators

For an overview of the aspired indicator set, Box 1 can be used. It represents the actual state of indicator selection and quantification. The list demonstrates that the set is under continuous development: The bold indicators have been calculated and quantified already, examples can be found in the following text and additional applications are available or worked out, i.e. referring to the outcomes of the MOLAND scenarios. The symbol (*) means that the indicator is still worked out, there are no examples available at present. This is the case for

- *additional integrity variables* which will be needed to construct a holistic picture of the environmental state. These indicators will be developed at the Ecology Centre by qualification theses which are standing outside the financial PLUREL support.
- *social indicators* which are still worked out on the base of the conjoint analysis: One result of these works is the identification of the significance of different features for the overall evaluation of the living conditions of urban and rural populations. As these analyses are still ongoing (e.g. by questionnaire samplings) their determination will be carried out in another deliverable. The results will be integrated in the XPLORER indicator fact sheets.
- *economic indicators*, which will be developed in the forthcoming periods. There is a delay due to change of the responsible institutions.

Box 1: Focal M4 indicator set

Land cover structures and dynamics

- Providing aggregated information on land use structures and intensities in rural-urban regions as input parameters for the assessments

Ecosystem Integrity Indicators:

- Providing integrated information on the environmental state of rural-urban regions

→ **Biodiversity potential - Breeding bird community (UFZ)**
→ **Carbon storage in vegetation and soil (UFZ)**
→ **Evapotranspiration (CAU)**
→ Landscape heterogeneity (CAU)*
→ Net primary production (CAU)*
→ CO2 production and carbon sequestration (CAU)*

Ecosystem Service Indicators:

- Providing selected information on land use based impacts on the potential of rural-urban landscapes to secure natural human living-demands

→ **Food provision (CAU)**
→ **Water provision (CAU)**
→ **Energy provision (CAU)**
→ **Climate regulation (UFZ)**
→ **Recreation - Availability of recreational green space (UFZ)**

Social Indicators:

- Providing information on social and demographic impacts and drivers in rural-urban regions

→ **Population density (CAU)**
→ **Settlement population density (CAU)**
→ **Household size (CAU)**
→ **Housing area per person (CAU)**
→ **Mean age (CAU)**
→ Quality of life basing on conjoint analysis (ECA) regarding

- Air quality*
- Access to public green spaces*
- Availability and access to public transport*
- Availability of shopping facilities*
- Noise pollution*
- Area safety and security*
- House or flat suitability*
- Waste collection*

Economic Indicators:

- Providing information on economic impacts and drivers in rural-urban regions

→ **Unemployment rate (CAU)**
→ **Commuting distance (SYKE)**
→ GDP (UBath)*
→ External costs green space (UBath)*
→ Costs carbon stock (UBath)*
→ Costs Air pollution (UBath)*

4.2 Land Cover Structures

As very important input data for the indicator system stem from land cover and land use information, these items will be described and illustrated in the following paragraph. The basic information source is the European Corine land cover map which originates from remote sensing data and includes 44 land cover classes (EEA 1994) which are arranged in 3 hierarchical levels. Whereas its rather coarse scale of 1:100000 represents a disadvantage of the data set, it offers the possibility to apply the same land cover data for all case study areas and compare them with each other. As the objective of Module 4 is to assess impacts of land cover / land use changes on environmental, social and economic indicators, we used the Corine land cover maps as input data for all exemplified indicator quantifications.

First, we analyzed the land cover structure of the different case studies and compared their spatial and temporal patterns. In order to investigate rural urban relationships, we developed rural urban gradients of the land cover units.

Quantification method

Rural urban land cover gradients were calculated for each case study region by creating 30 concentric buffer rings around the city centres with outer radii of 1km to 30km and a diameter of 1km each in GIS ArcView, using the Corine land cover maps (EEA 1994). For each buffer ring, percentage values of the main Corine land cover classes (highest hierarchical level) in comparison of the total buffer ring area were calculated.

Exemplary results

The following maps (Figures 18 to 29) are showing the land cover distribution of the six European case study regions in the year 2000, including the concentric area with a radius of 30km for which the rural urban land cover gradients were calculated. The rural urban land cover gradients reveal basic differences of the case study regions. First of all, the sizes of the city areas differ considerably. Whereas in the Koper case study area, the urban fabric gradient reaches its minimum at a distance of only 3 kilometers from the city centre, this gradient is still decreasing at a distance of 30km in the Manchester case study. The urban fabric gradients give also hints about the urban typologies. Monocentric cities such as Montpellier exhibit a steeply decreasing urban fabric gradient, whereas the urban fabric gradients of polycentric cities such as The Hague show several maxima which are not falling below the national average value of artificial surface until the gradient reaches the next city, indicating that The Hague does not have a "real" rural hinterland. Hence, the land cover gradients are visualizing the fact that rural urban relationships vary strongly from case study to case study. The gradients also give a first overview about the amount of green and water area in the city centre as well as their rural urban distribution. These two land cover types are considered to provide a high recreational service and are further analyzed in the ecological indicator "recreation". The case studies differ not only in the amount and distribution of artificial surfaces, but also in the dominating land cover types in their suburban and rural surroundings. Whereas in the hinterlands of Leipzig, Warsaw, The Hague and Manchester, the agricultural area plays a major role, the surroundings of Montpellier and Koper are dominated by forests and semi-natural areas. These land cover distributions have an important impact on the provision of ecosystem services, which will be further analyzed by the ecological indicators.

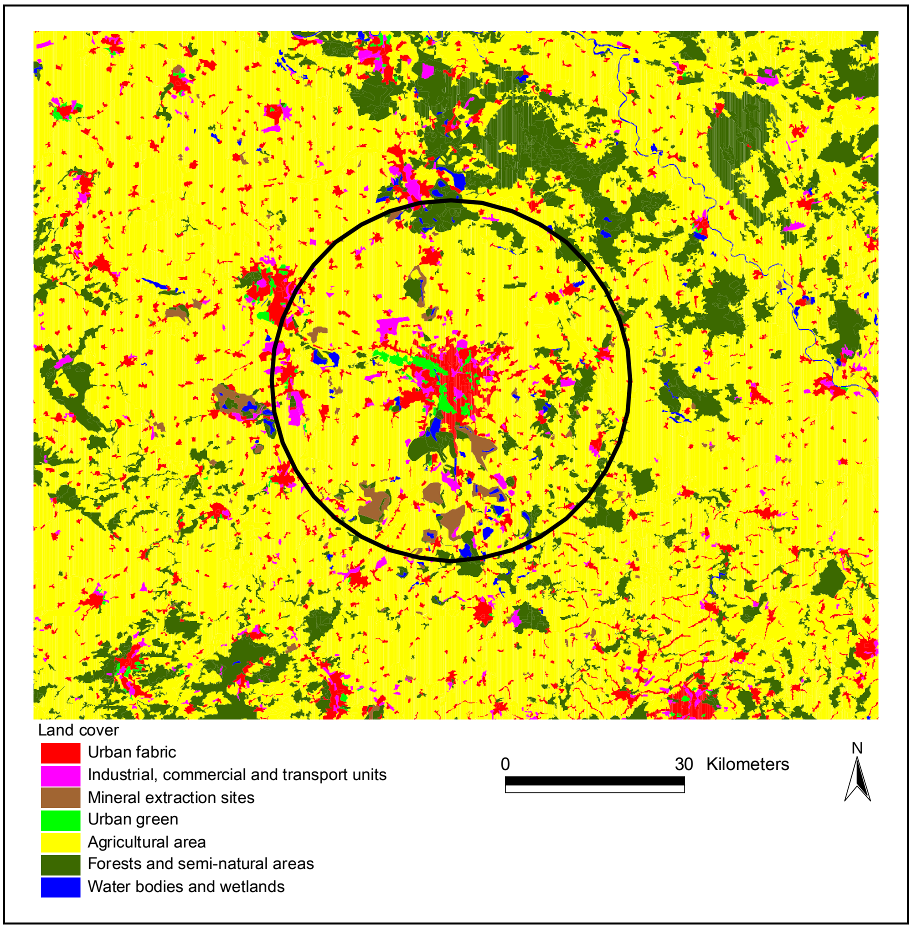

Figure 18: Corine Land Cover (year 2000) map of the Leipzig case study including a buffer ring with a radius of 30km used for the land cover gradient calculation

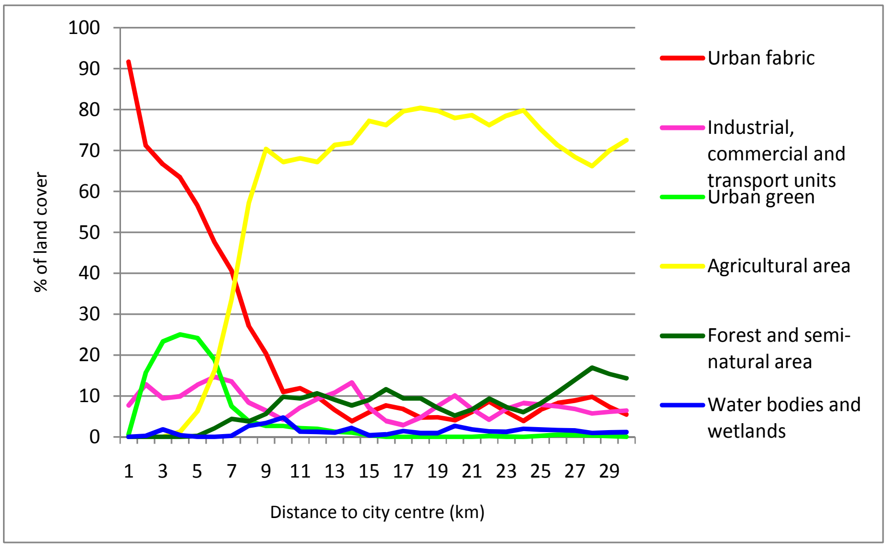

Figure 19: Rural urban land cover gradients of the main Corine land cover classes for the Leipzig case study, year 2000

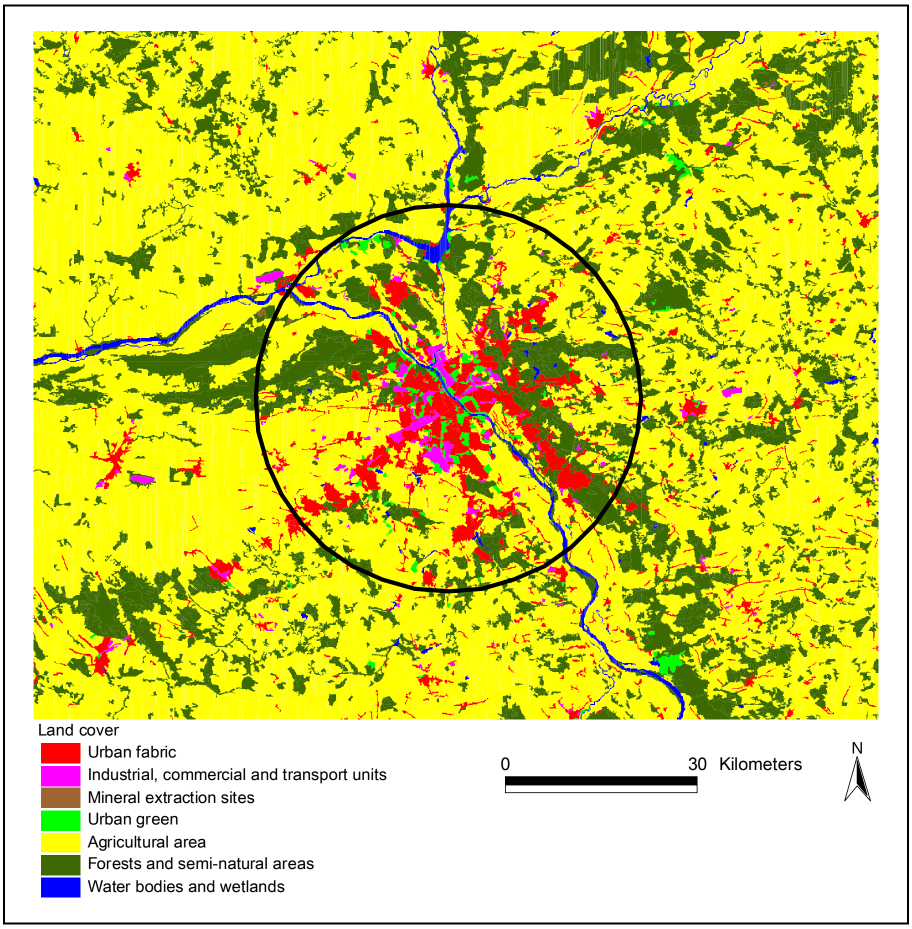

Figure 20: Corine Land Cover (year 2000) map of the Warsaw case study including a buffer ring with a radius of 30km used for the land cover gradient calculation

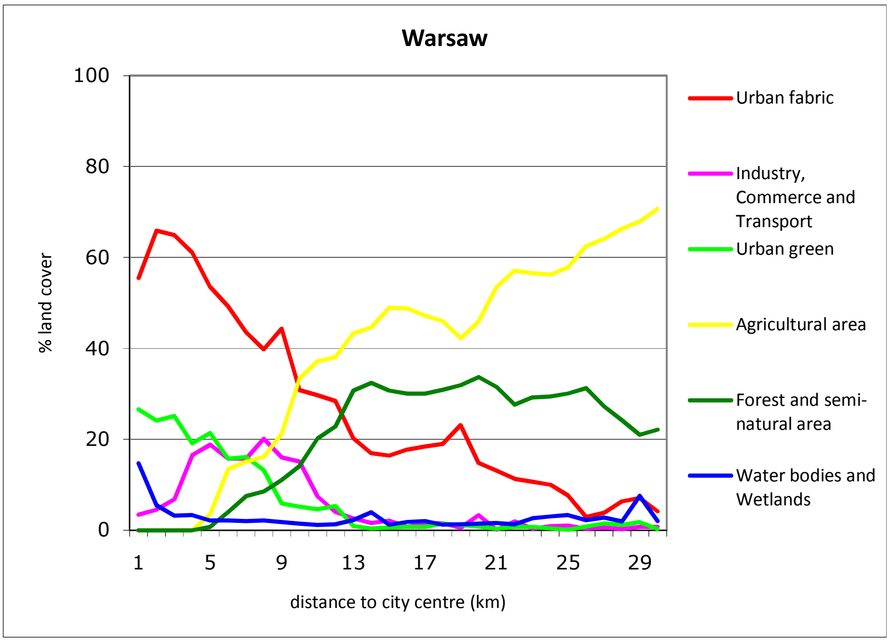

Figure 21: Rural urban land cover gradients of the main Corine land cover classes for the Warsaw case study, year 2000

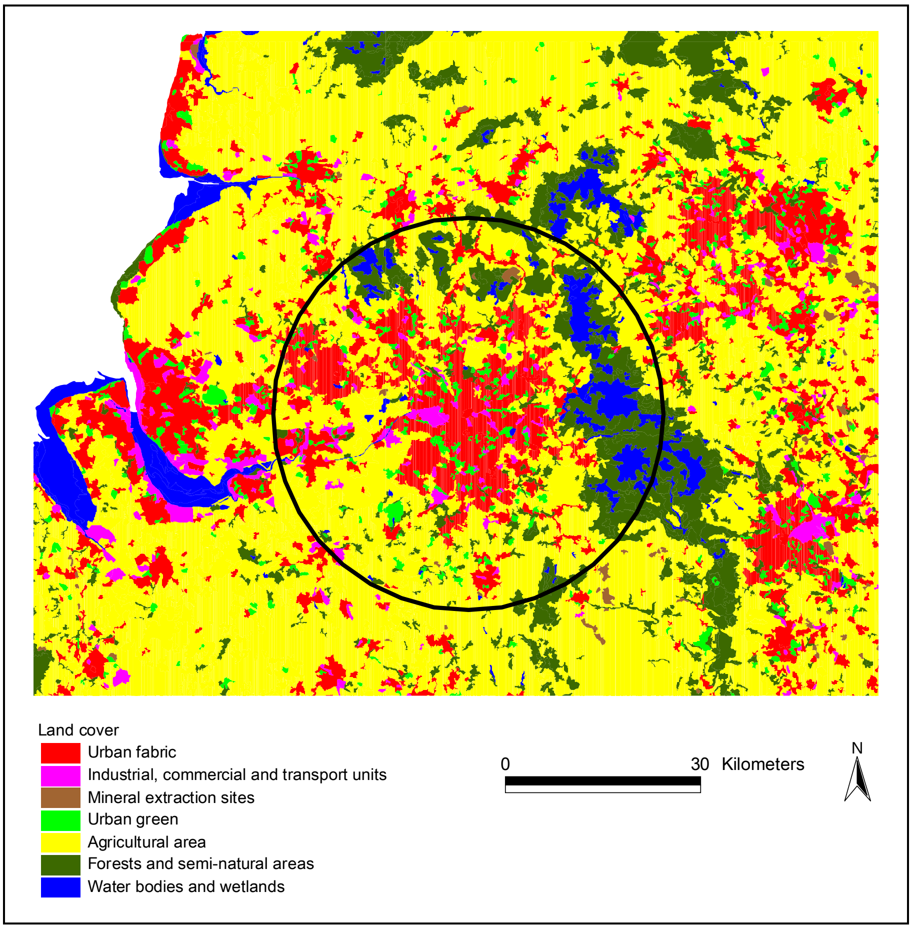

Figure 22: Corine Land Cover (year 2000) map of the Manchester case study including a buffer ring with a radius of 30km used for the land cover gradient calculation

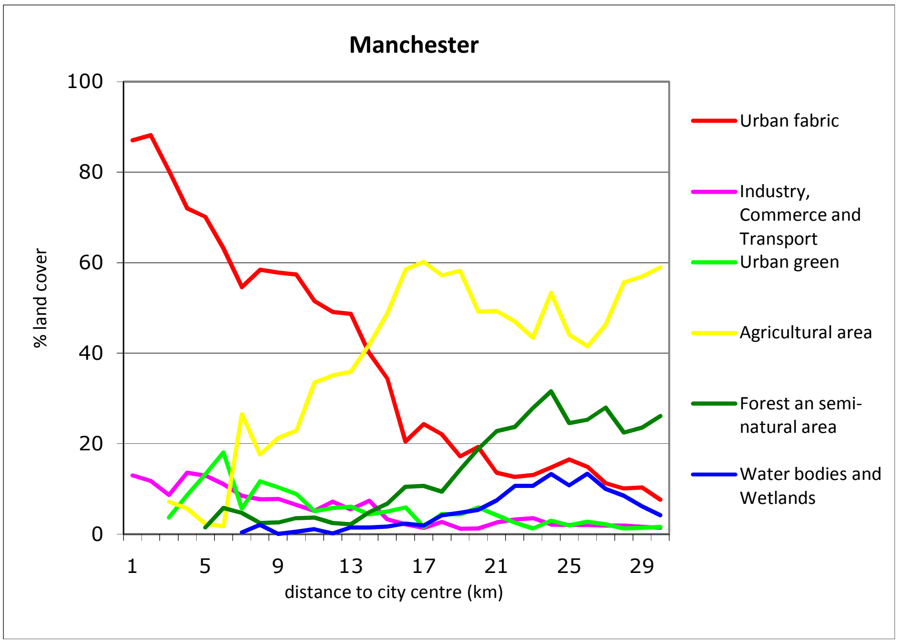

Figure 23: Rural urban land cover gradients of the main Corine land cover classes for the Manchester case study, year 2000

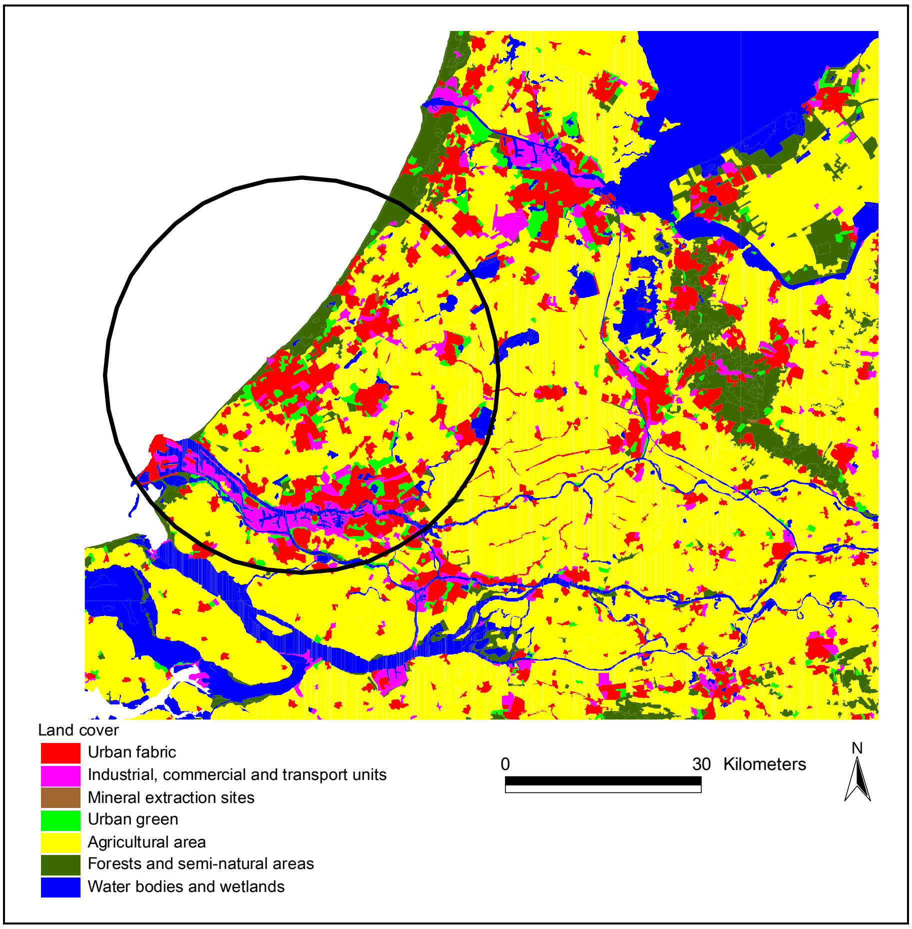

Figure 24: Corine Land Cover (year 2000) map of The Hague case study including a buffer ring with a radius of 30km used for the land cover gradient calculation

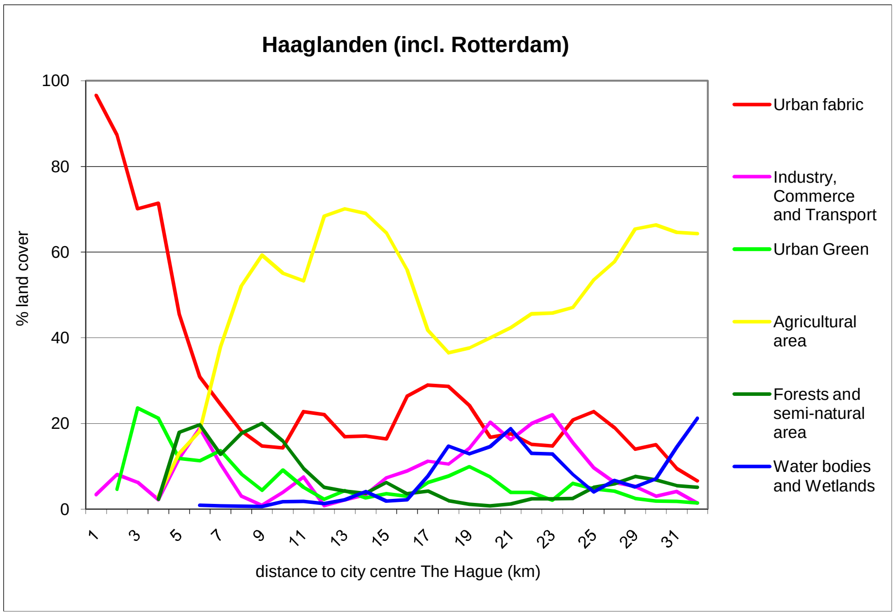

Figure 25: Rural urban land cover gradients of the main Corine land cover classes for The Hague case study, year 2000

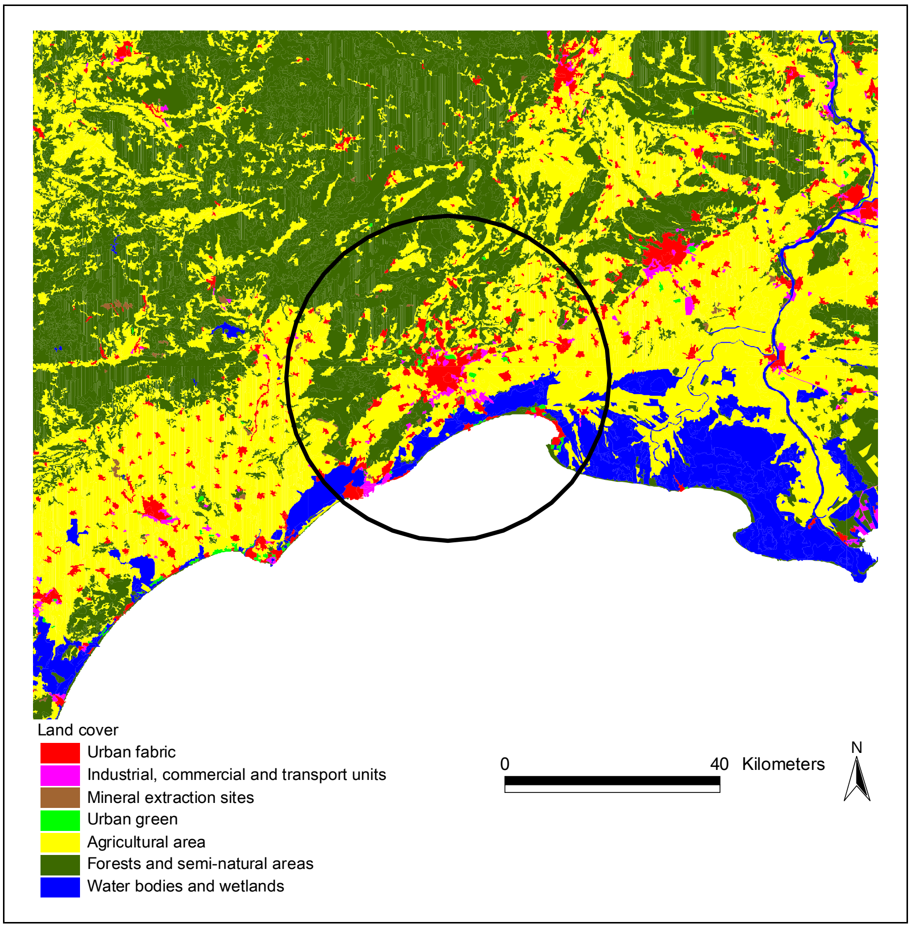

Figure 26: Corine Land Cover (year 2000) map of the Montpellier case study including a buffer ring with a radius of 30km used for the land cover gradient calculation

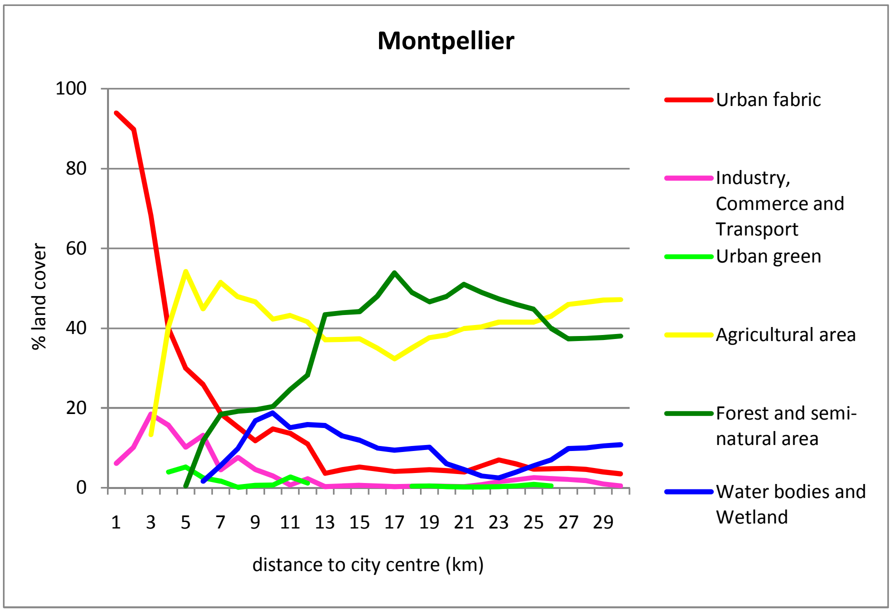

Figure 27: Rural urban land cover gradients of the main Corine land cover classes for the Montpellier case study, year 2000

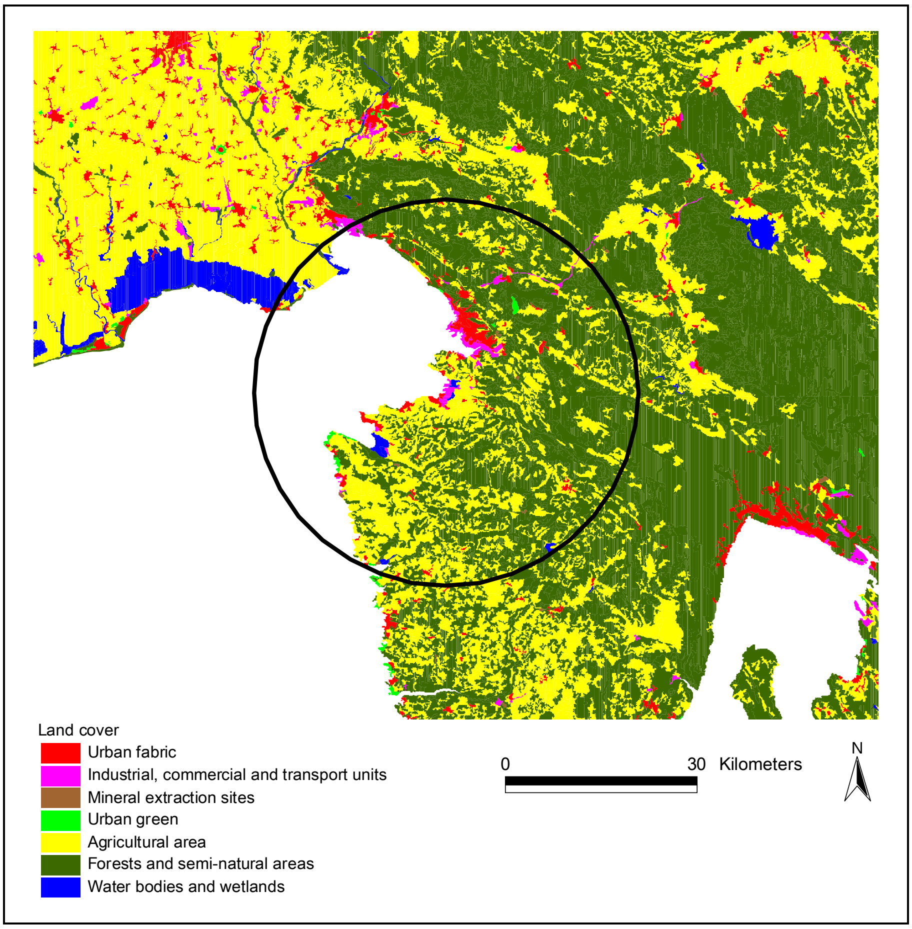

Figure 28: Corine Land Cover (year 2000) map of the Koper case study including a buffer ring with a radius of 30km used for the land cover gradient calculation

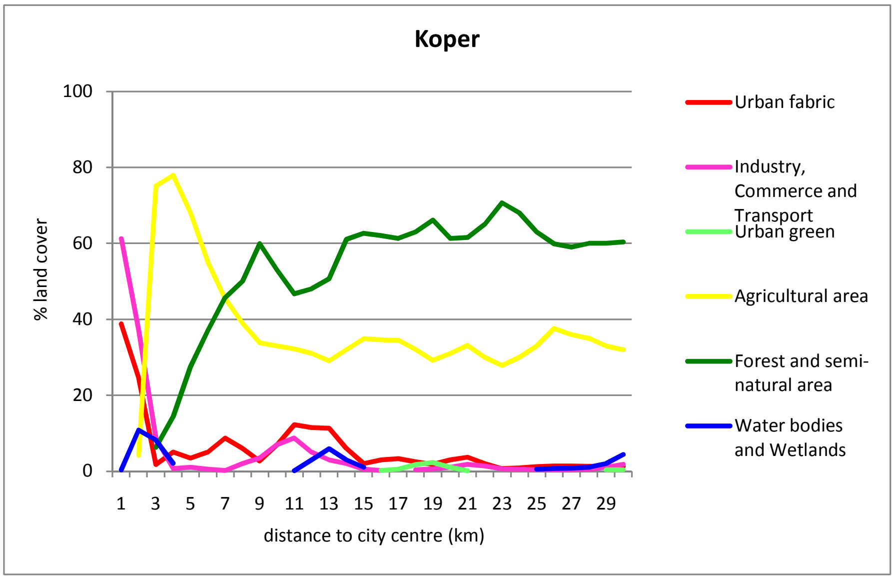

Figure 29: Rural urban land cover gradients of the main Corine land cover classes for the Koper case study, year 2000

The land cover distribution of the case study areas have been interpreted with different landscape ecological methods. An interesting example for these study results is the development of an urban sprawl indicator, which is sketched in the following section. Additional interpretations are recently carried out by calculating several features of landscape metrics.

Urban sprawl indicator

Definition

Urban sprawl is defined by the EEA (2006) as "... low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas." We developed a simple indicator of urban sprawl, using the land cover gradients and the population number as input data.

Quantification method

Total population [mio]/Distance from the city centre (determination of a threshold value where the amount of artificial surface reaches the national mean value) x (1/Distance from the city centre where the natural surfaces exceed the artificial surfaces) x 100

This formula, which puts the population number in relation to the land cover structure, results in a value which decreases with the increase of uban sprawl.

Exemplary results

Up to now, land cover gradients and resulting urban sprawl indicators have been calculated for all case studies for the year 2000, allowing a comparison of the different case studies. A calculation of the indicator for different MOLAND land cover scenarios will follow.

Tab. 11: Urban sprawl indicator results for all case studies, year 2000

Case study	Urban sprawl indicator value for year 2000
Leipzig	**0.36**
Manchester	**0.62**
Warsaw	**0.59**
Koper	**0.33**
The Hague	**0.61**
Montpellier	**0.38**

4.3 Ecological Indicators

In the following section, each environmental key indicator (climate regulation, recreation, biodiversity potential, carbon storage, food provision, water provision, energy provision, evapotranspiration) will be described by a definition, the quantification method and the indicator's significance for rural urban regions. Additionally, exemplary results of the quantification are shown in form of maps and/or rural urban gradients.

4.3.1 Ecosystem Integrity

The basic concept of Ecological Integrity has been described in chapter 2.2. It represents the ability of ecosystems and landscapes to develop on the base of self-organizing processes. The ecosystem theoretical findings about integrity require a depiction of more than 5 items, because the potential of landscape units to provide these "supporting ecosystem services" (which in fact are identical with the integrity variables) can not be assessed on the basis of isolated variables. The tested and applied variables comprise of the biodiversity potential, carbon storage, and evapotranspiration. To reveal a complete picture, additional quantifications are conceived concerning landscape heterogeneity, net primary production and CO_2 balances. By elaborating these parameters, the holistic demands of the integrity principle can be fulfilled, and the whole set can be understood as one integrative variable.

Biodiversity potential

Definition "Biodiversity potential"

Biodiversity is the variability of living organisms and takes into account the ecosystems of which they are part. In general, it covers a wide range of scales – from genes to ecosystems. Biodiversity is the basis for all ecosystem functions and services and therefore directly linked to human well-being. Biodiversity is closely connected to land cover and land use and a change of both has an impact on it. Because biodiversity is so broadly defined, we focus on the potential of the landscape to provide habitat for diverse species communities. We call this the biodiversity potential.

Quantification method

We used breeding bird species that indicate diverse habitats for the assessment of the biodiversity potential. Habitat models that build on the statistical relationship between the simplified CORINE land cover and the presence and absence of the indicator species were developed. Many models were then combined to estimate the probability that an area is occupied by many of those species. This value is the biodiversity potential. If the value is 1, the Biodiversity potential is highest, is it 0 the potential is lowest. The models can be applied to different land cover maps or land cover scenarios. Thus the potential impacts of land cover change on biodiversity can be studied.

Significance for rural urban regions

Biodiversity in rural–urban regions is a key for the provision of local ecosystem services. Rural-urban regions often have a high land cover and land use diversity that favours rich Biodiversity. Land-cover change has led to a decline of Biodiversity in many parts of the world, including Europe. Pressure from land-cover change is especially high in rural-urban regions.

Exemplary results

Currently, the biodiversity potential was computed solely for the Leipzig case study and selected scenarios, including land uses 1990, 2000, PLUREL scenario Hypertech (year 2025). The map shows the biodiversity potential for forest species in 1990. As the area is mainly covered by agricultural land, there are only few places with a high biodiversity potential. These areas are of great importance for the biodiversity of the region.

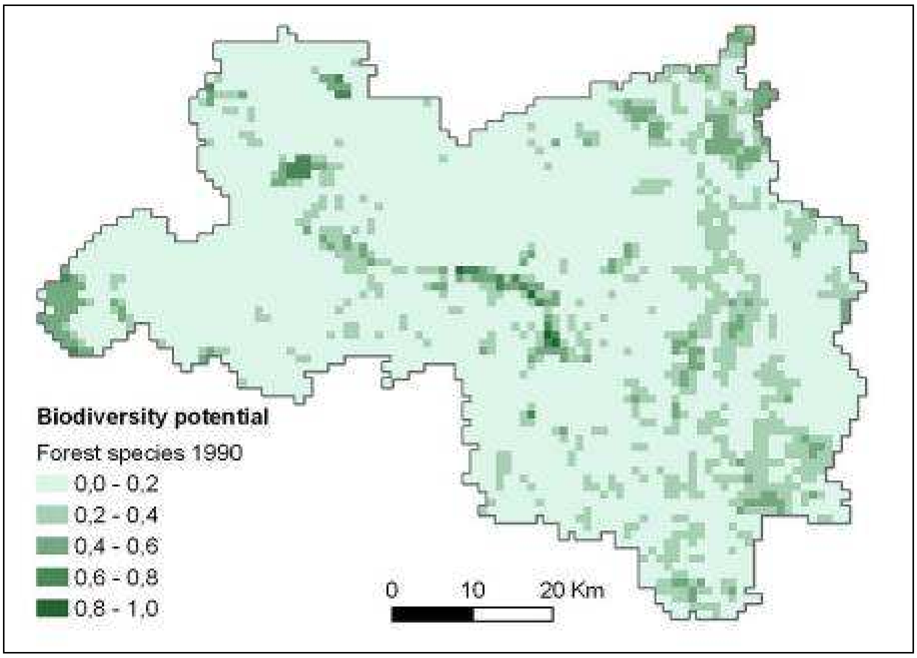

Figure 30: Biodiversity potential for forest species in the Leipzig case study region, year 1990.

Carbon storage

Definition "Carbon storage"

Terrestrial carbon, stored in living and dead biomass and in soils, is an important part of the global carbon cycle. Atmospheric carbon can be sequestered into the terrestrial stock by plants and released from it by decomposition and burning. The amount of stored carbon varies across different land-cover types and geographical regions. Land cover change from an ecosystem with high carbon storage to an ecosystem with low storage leads to the release of carbon to the atmosphere and vice versa.

Quantification method

We derived average carbon storage for the simplified CORINE land cover classes from literature and own observations. These values can be linked to different maps and land cover scenarios and the emissions caused by land-cover change can be estimated.

Significance for rural urban regions

Land use and land cover change is a major source of anthropogenic carbon dioxide emissions. Land cover change in rural-urban regions is therefore directly linked to the global carbon cycle and the issue of climate change.

Exemplary results

Currently, preliminary results for the above ground carbon storage in the Leipzig case study were computed. Results for all other Leipzig scenarios and all other European PLUREL case studies will follow. They will include soil carbon storage.

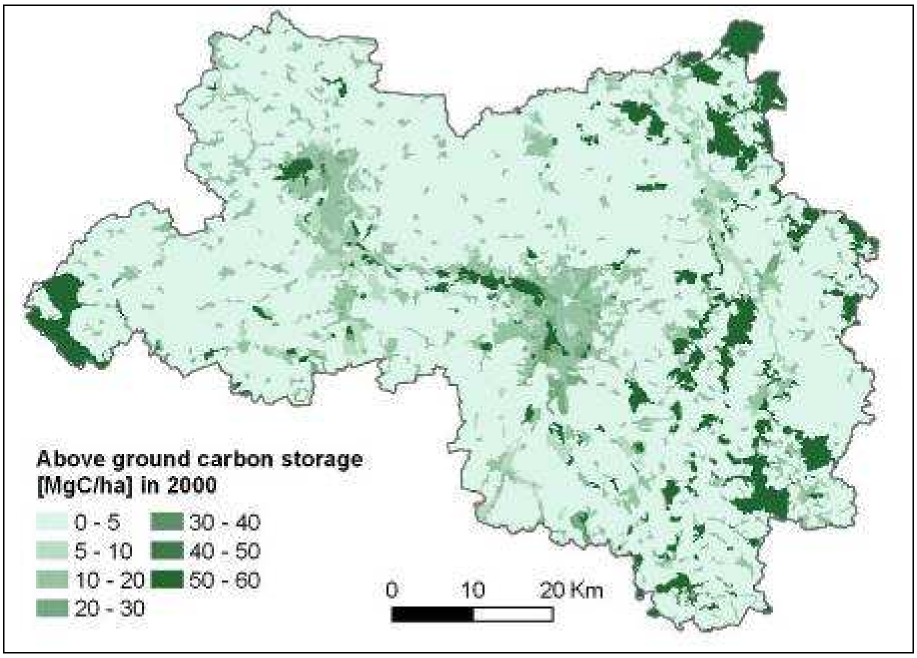

Figure 31: Above ground carbon storage in the Leipzig case study region, year 2000.

Evapotranspiration

Definition “evapotranspiration”

The evapotranspiration as part of the hydrological cycle is an important ecosystem integrity indicator and is strongly related to land cover types. The indicator is quantified in mm/day*m².

Quantification method

Evapotranspiration is calculated in mm/day*m² per land cover type using the Haude formula (terrestrial land cover types) and the Blaney-Criddle formula (aquatic land cover types). Temperature data and relative humidity data are used for the years 1990 and 2000 from the German meteorological service. For the scenario calculation, mean values for 1979-2008 are applied. The rural urban gradients are calculated by producing twenty concentric buffer rings around the city centre of Leipzig with a diameter of 1km each. Input variables: Corine Land Cover, MOLAND scenarios, Mean temperature, Mean relative humidity, Mean temperature at 2pm, Haude factor per land cover type, Mean daily percentage of total annual day time hours; Output variables: Potential evapotranspiration in mm/day*m² per land cover type.

Significance for rural urban regions

The process of evapotranspiration consumes energy and therefore has a cooling effect and a positive impact on micro climate regulation. This is especially important in cities, which often suffer from the so called "urban heat island" effect due to their high amount of sealed surfaces. Land use changes in peri-urban regions have a direct effect on evapotranspiration and thereby on micro climate regulation and quality of life.

Exemplary results

Up to now, the evapotranspiration was calculated for the case study region of Leipzig for the years 1990, 2000 and several MOLAND scenarios. Figure 32 shows an exemplary result for the MOLAND business as usual scenario, year 2010. Results for other case study regions will follow. The evapotranspiration is strongly related to land cover types. Wetlands and water bodies show the highest evapotranspiration, followed by coniferous forests, pastures and urban green, broad-leaved forests and agricultural areas. Artificial surfaces are characterised by the lowest evapotranspiration. Therefore, a clear rural urban gradient of evapotranspiration can be observed. However, the climatic changes between the considered years have a stronger impact on changes in evapotranspiration than land use changes. Evapotranspiration is the lowest in the city centre of Leipzig and increases with distance from the centre, due to the higher amount of natural land cover types in suburban and rural areas. Although the climatic differences have a stronger influence on changes in evapotranspiration in the considered years, ongoing soil sealing in the peri-urban region has a negative impact on evapotranspiration and micro climate regulation. Against the background of global climate change, it is especially important to increase evapotranspiration in the city centres and peri-urban regions by preserving and enlarging green areas, which can also be done by roof top and facade greenery.

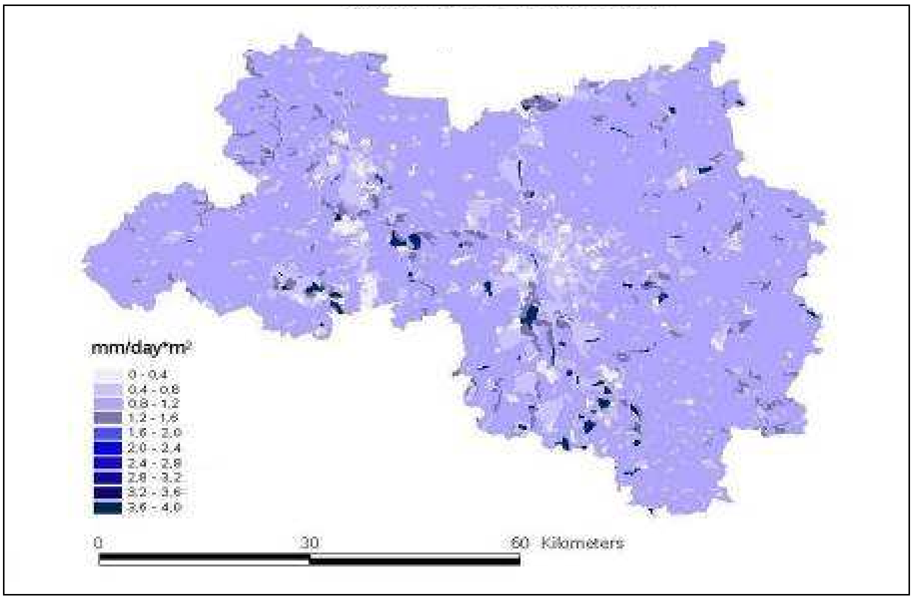

Figure 32: Evapotranspiration in mm/day*m² in the case study Leipzig-Halle, MOLAND business as usual scenario for year 2010

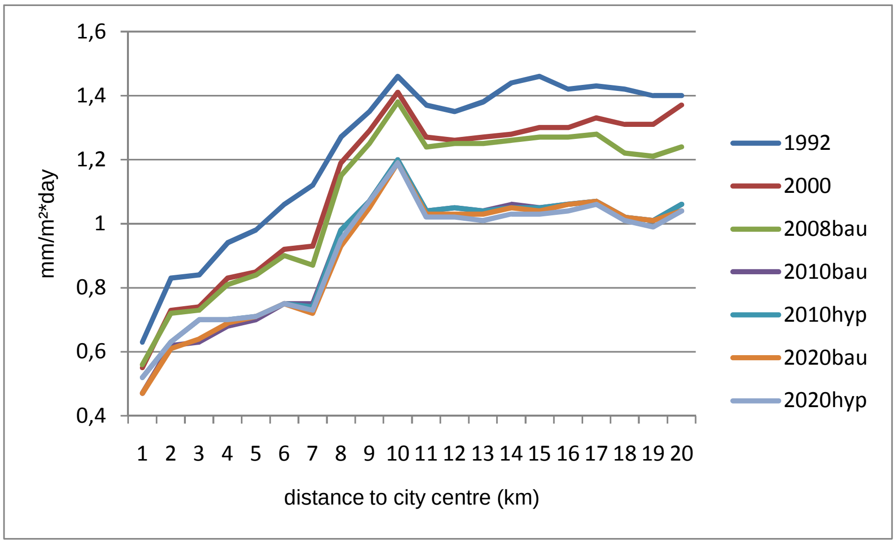

Figure 33: Rural urban gradients of evapotranspiration in Leipzig for the years 1992, 2000, and several scenarios.

4.3.2 Ecosystem Services

The focal linkage of environmental and human systems is provided by the ecosystem service approach. To depict the potential of ecosystems and landscapes to deliver goods and services, the indicators food provision, water provision, energy provision, climate regulation and recreation have been selected.

Food provision

Definition "food provision"

The indicator describes the amount of food production in GJ/ha for the food producing land cover types (arable land, pastures, fruit trees and berry plantations, forests).

Quantification method (for the Leipzig-Halle case study region)

The food supply was quantified in GJ/ha land cover type in order to include an additional qualitative aspect of the produced food in comparison to yields in t/ha. Statistical data on crop yield per hectare as well as crop type composition (wheat, rye, barley, oat, triticale, corn, silage maize, grass, rape seed, turnips, and potatoes), fruit yield per hectare, grass yield per hectare and game shot per hectare were applied for calculating average values of food production per land cover type. The amount of grass produced per hectare pasture was converted into meat and milk that can potentially be produced with the grass fodder per hectare, considering the actual livestock composition in the region. For pastures, forests and fruit trees and berry plantations, average food supply values at Federal State level were calculated per hectare land cover type. Regarding the food production on arable land, average yields per hectare were calculated at district level, considering the percentages of different crop types. Fodder crops (silage maize, grass, barley, oat and triticale) were considered with only 10% of their energetic value, as 90% of the food energy is lost when producing meat out of fodder plants. The percentage of non-food crop production (e.g. bio energy crops) on arable land was estimated and excluded from the calculation. In order to differentiate the food production on arable land according to the soil fertility, soil fertility maps containing an index of the soil's yield potential were applied. A bi-variate regression and correlation analysis to investigate the relationship between the aggregated soil fertility index at district level and the crop yield at district level with n=24 districts of Saxony and Saxony-Anhalt was conducted. For those crops and years, for which a significant correlation between crop yield and soil fertility index was found, a correction of results was conducted using the soil fertility maps and the determined regression curves. After having calculated the food production per hectare in tons, we multiplied it with the energetic value of the respective food, based on the conversion factors used by the United Nations FAO statistics database, resulting in GJ/ha.
Using the derived maps of food provision and additional food demand data, we quantified rural urban gradients of food supply and demand. 20 concentric buffer rings with an outer radius of 1 to 20km and a diameter of 1km each were created around the city centre of Leipzig with help of the commercial GIS software ArcView, ESRI. For each buffer ring, an average food provision/demand value per hectare was then calculated in order to be able to compare the different buffer rings which do not exhibit the same absolute sizes.

Significance for rural urban regions

"Food provision" is a fundamental ecosystem service, which has to be provided by rural areas to supply the urban population with food. The higher the percentage of consumed food that is produced in the region, the lower the energy costs for transportation and the export of environmental and social problems into other regions of the world. Recent changes in land cover and land use intensity in rural urban areas have important impacts on the food provision, e.g. the sealing of fertile soils due to urban sprawl.

Exemplary results

Food production in the Leipzig case study region (in GJ) increased from 1990 to 2000 and again to 2007 due to a higher productivity per hectare and a decrease in animal stocks and thus less fodder production, which results in a higher amount of food energy directly usable by humans. These two processes have a stronger influence on the food production development than the parallel ongoing increase of bio energy crops on arable land. The decrease of agricultural land in the region due to urban sprawl does not have a visible effect on the total food production as it is more than outweighed by the increased productivity. However, the expansion of urban area occurs on the most fertile soils which are located around the city centres, especially around Halle. Up to now, results have been computed for the Leipzig-Halle case study region for the years 1990, 2000, and 2007 (a map for the year 2000 is shown as an example in Figure x). Results for MOLAND scenarios until year 2025 for the Leipzig-Halle case study will follow.

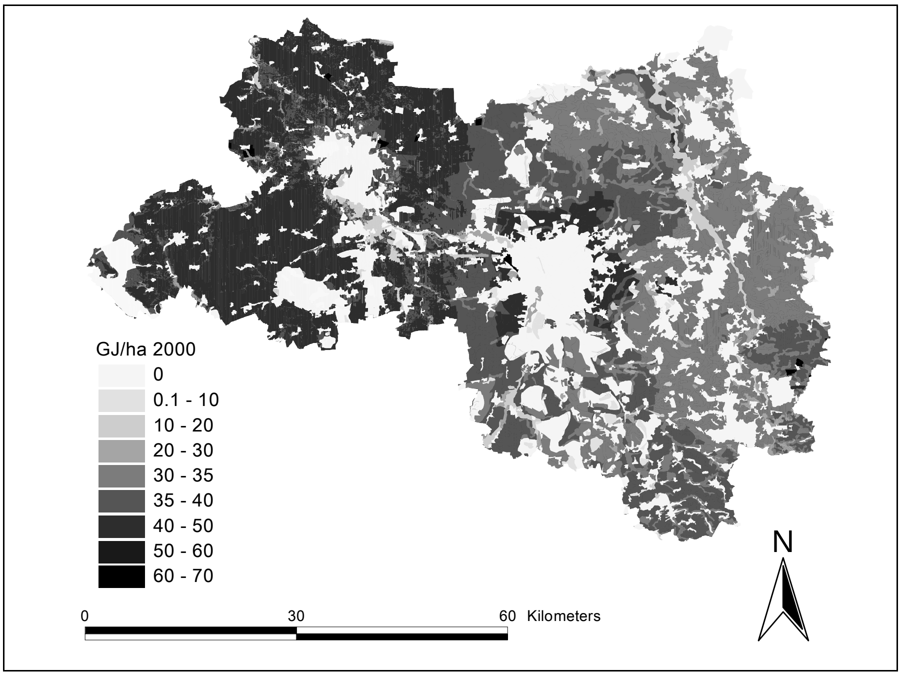

Figure 34: Food supply in GJ/ha in the case study region Leipzig-Halle, year 2000.

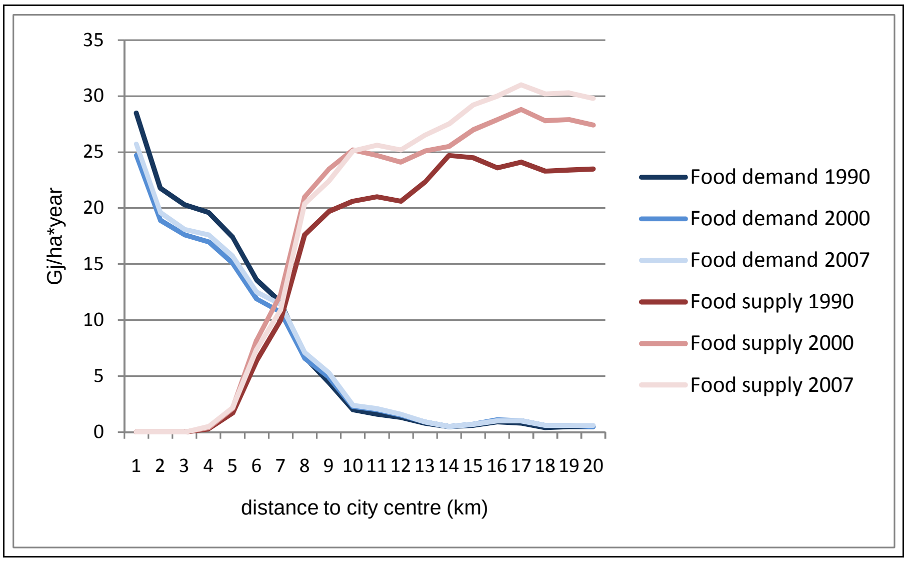

Figure 35: Rural urban gradients of food demand and supply for Leipzig in years 1990, 2000, 2007

Water provision

Definition "water provision"

The indicator describes the amount of clean water (filtered by the soils) in m^3/ha that is supplied by ecosystems via groundwater recharge.

Quantification method

The groundwater recharge was chosen as an appropriate indicator to represent the ecosystem service water supply. For its calculation, it was necessary to find a suitable method being sensible to land cover changes in order to reflect their impact on the water supply. As a method that fulfils this need and is still applicable with easy to access data, the TUB-BGR method (Wessolek et al. 2004) was applied. The output of this method is the mean annual percolation rate, thus including groundwater recharge as well as interflow. The following input data were used:

- Medium corrected annual precipitation
- Medium corrected precipitation in summer
- Medium potential evapotranspiration as grass reference evapotranspiration
- Groundwater level
- Usable field capacity
- Actual root depth

Based on these input variables, the TUB-BGR method calculates the mean annual percolation rate in mm/m^2*a with help of regression functions for arable land, grassland, broad-leaved forest and coniferous forest. Thus, the Corine Land Cover classes had to be re-classified into these four categories. For water bodies, urban fabric and industrial, commercial and transport units, no percolation is assumed as an approximation, although the sealing rate of artificial surfaces in the Leipzig region varies between 40-60% for large housing estates (flats and houses), 60-80% for 1990s housing estates and older villages and 80-100% for centers, commercial space and roads (Haase and Nuissl, 2007). Hence, although infiltration and groundwater recharge is drastically reduced in urban areas (Decker et al. 2000) the groundwater recharge for these areas is somewhat underestimated. For a detailed analysis of the relation between groundwater recharge and percentage of sealed surface in Leipzig see Haase (2009). The calculated water supply was then converted into m^3/ha and mapped at a 1x1km resolution; negative values were set to zero in the water supply map.
Using the derived maps of water provision and additional water demand data, we quantified rural urban gradients of water supply and demand. 20 concentric buffer rings with an outer radius of 1 to 20km and a diameter of 1km each were created around the city centre of Leipzig with help of the commercial GIS software ArcView, ESRI. For each buffer ring, an average water provision/demand value per hectare was then calculated in order to be able to compare the different buffer rings which do not exhibit the same absolute sizes.

Significance for rural urban regions

The water provision is especially important in rural urban regions, as the urban population, industry and commerce consume a large amount of water, which cannot be imported from far distant regions. Groundwater is especially suitable for urban water provision, as the water has already been cleaned by soils. However, the groundwater recharge decreases due to additional soil sealing at the urban fringe. Thus, urban sprawl has a negative impact on the water provision in rural urban regions.

Exemplary results

The water supply decreased from 1990 to 2000 and again to 2007 due to additional soil sealing, which reduced the percolation rate especially at the urban fringe. Until now, the water supply for the case study region of Leipzig for the three years 1990, 2000 and 2007 has been calculated (an exemplary map for the year 2000 is shown in Figure x). Results for the MOLAND scenarios until year 2025 for the case study region Leipzig-Halle will follow as well as water provision maps for the other case study regions using a simplified calculation method.

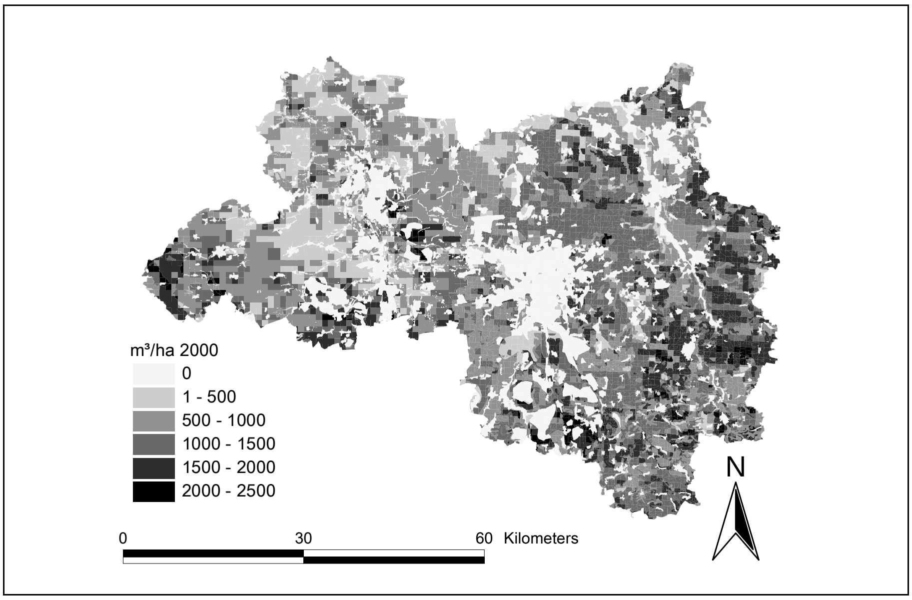

Figure 36: Water supply in m³/ha in the case study Leipzig-Halle, year 2000

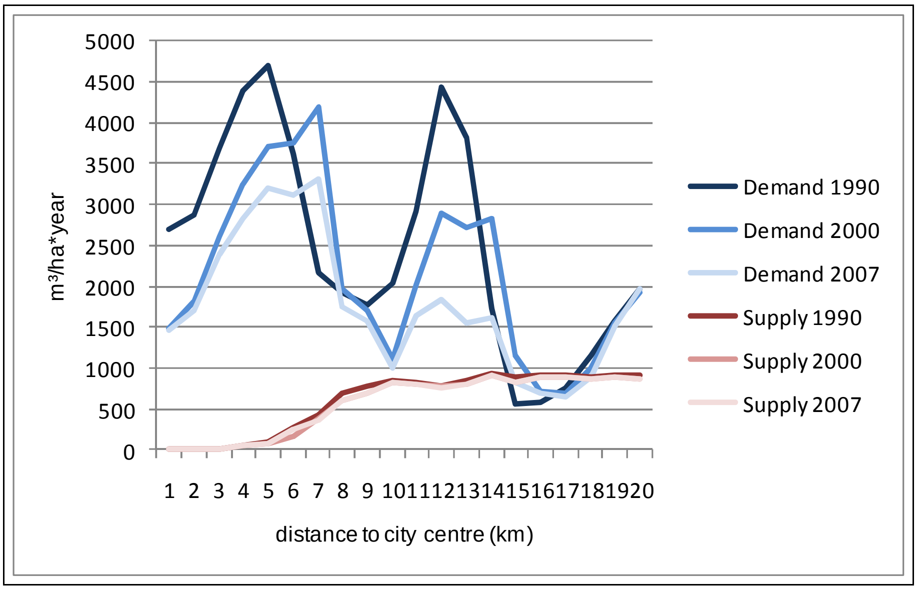

Figure 37: Rural urban gradients of water demand and supply for Leipzig in years 1990, 2000, 2007

Energy provision

Definition "energy provision"

The indicator describes the amount of human used energy in GJ final energy/ha that is produced on the different land cover types.

Quantification method (for the Leipzig-Halle case study region)

The energy supply was calculated in GJ final energy per hectare land cover type. First, the energy sources used for energy conversion purposes at the different time steps were identified and assigned to the corresponding land cover types responsible for the energy provision.

The solar energy was assigned to urban, industrial and commercial areas, as solar energy plants in the region were mainly located on buildings during the time span under consideration. The energy provision was calculated on municipality level for each time step as follows: Installed power of solar energy plants in municipality x (MW) * 640h (2000), 806h (2007) * 3.6 / urban, industrial and commercial area (ha) in municipality x = GJ/ha urban, industrial and commercial area in municipality x.

The wind energy was assigned to arable land as wind power plants are assumed to be mainly located on arable land. Again, the wind energy is calculated on municipality level for each time step: Installed power of wind energy plants in municipality x (MW) * 2000h * 3.6 / agricultural area (ha) in municipality x = GJ/ha agricultural area in municipality x. The number of full load hours is estimated as 2000h per year after the German WindEnergy Association (www.wind-energie.de). For water energy plants, this number is estimated after Möhr et al. (1998) as 4000h, leading to the following calculation formula: Installed power of wind power plants in river section x (MW) * 4000h * 3.6 / river area in river section x (ha) = GJ/ha river area.

The bio energy provision was assigned to the land cover classes arable land (bio energy crops) and forests (wood). Due to data availability, an average value per ha arable land respectively per ha forest had to be calculated. The calculation procedure can be summarized by the following formula: Total area of bio energy crops * final energy produced per crop type and hectare / total agricultural area (ha) = GJ /ha agricultural area.

As non renewable energy, the only but intensively used source in the region was brown coal that was extracted from several big open cast mining sites. Although the extracted amount of brown coal per hectare as well as its energetic value differs from site to site, an average value per hectare mineral extraction site was calculated. An efficiency factor of 36% was assumed for the conversion of raw brown coal to final energy, leading to the following formula: Brown coal extracted (t) * energetic value of brown coal (GJ/t) * 0.36 / total area of mineral extraction sites (ha) = GJ/ha mineral extraction site.

Using the derived maps of energy provision and additional energy demand data, we quantified rural urban gradients of energy supply and demand. 20 concentric buffer rings with an outer radius of 1 to 20km and a diameter of 1km each were created around the city centre of Leipzig with help of the commercial GIS software ArcView, ESRI. For each buffer ring, an average energy provision/demand value per hectare was then calculated in order to be able to compare the different buffer rings which do not exhibit the same absolute sizes.

Significance for rural urban regions

Energy provision is an important ecosystem service, especially for urban regions, which are the world's main energy consuming regions. Many land cover types in the rural urban regions themselves have the capacity to provide renewable energy and thereby to contribute to a sustainable development. Therefore, it is essential to analyse, how land use changes in rural urban regions can influence the regional amount of energy provision.

Exemplary results

The energy provision in the case study region has changed considerably from 1990 to 2007. In 1990, the only energy source used in the region was brown coal. In the following years, the amount of brown coal extracted reduced, and renewable energy sources were more and more used. In the year 2000, a small amount of energy per hectare is produced on arable land (bio energy crops and wind energy plants), urban and industrial area (solar energy plants) and water area (water energy plants), with wind energy being the most important renewable energy source. In the year 2007, the use of all renewable energy sources increased, especially the use of wind energy in the western part of the case study area. Still, brown coal remains the most important energy source. Currently, results for the Leipzig-Halle case study region for the years 1990, 2000 and 2007 have been computed (Fig. 37 shows an exemplary result map for the year 2000), MOLAND scenario results until year 2025 will follow.

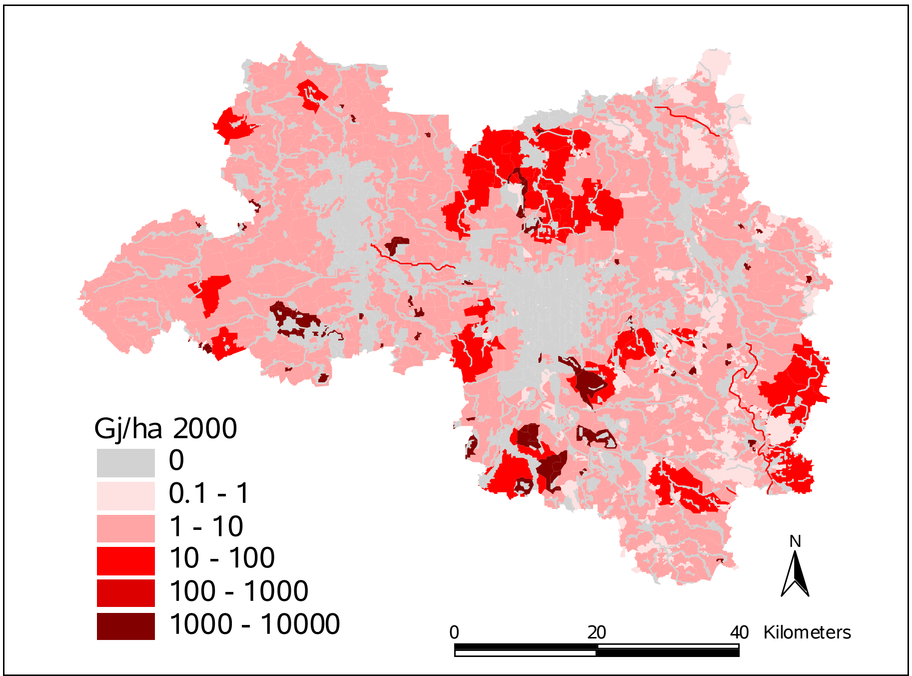

Figure 38: Energy provision in GJ/ha in the case study area of Leipzig-Halle, year 2000.

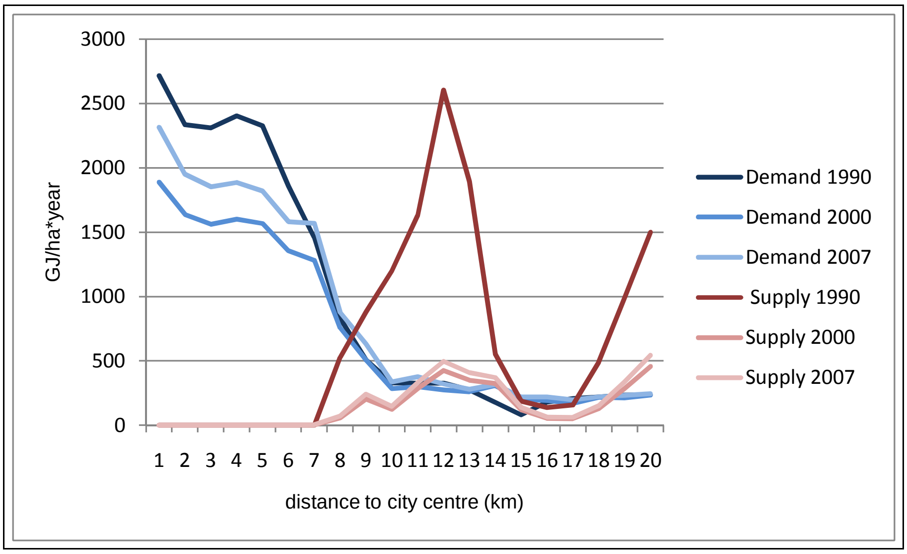

Figure 39: Rural urban gradients of energy demand and supply for Leipzig in years 1990, 2000, 2007

Climate regulation

Definition of „Climate regulation"

Local climate regulation encompasses the positive effects of green and blue areas on local air temperatures. It is quantified using thermal emissions of different land use classes.

Quantification method

The following index is created for each land use i to show differences in thermal emissions between land use classes:

emissionIndex[i]=emission[i] / emission [forest] • 100 – 100

The method uses lookup-tables that link land cover classes to land surface emissivity. Land surface emissivity stems from Landsat remote sensing data. For assessing impacts of land use changes in a given case study, (1) the case-study specific look-up table is needed as an input, plus (2) quantified information on land use change. The latter can be either (2.1) a table with changes in km² or (2.2) a GIS map. Land use change information has to use MOLAND land cover classes to be compatible with the lookup table. The output format depends on the input and is either a table (input 2.1) or a map (input 2.2) of indexed land surface temperatures.

Significance for rural urban regions

Local climate regulation is an important urban ecosystem service: Green areas like parks, urban forests, lawns and gardens as well as water surfaces of streams, lakes and ponds provide fresh and cool air for the population.
Accordingly, local climate regulation is a valuable service for the inhabitants of a rural-urban region, because it reduces the extent of the urban heat island and is therefore important for maintaining urban quality of life and adapting rural-urban regions to climate change.

Exemplary results

Currently, impacts of land use changes were computed solely for the Leipzig case study and selected scenarios, including land uses 1990, 2000, PLUREL scenario Hypertech (year 2025). Results for all other Leipzig scenarios and all other European PLUREL case studies will follow.

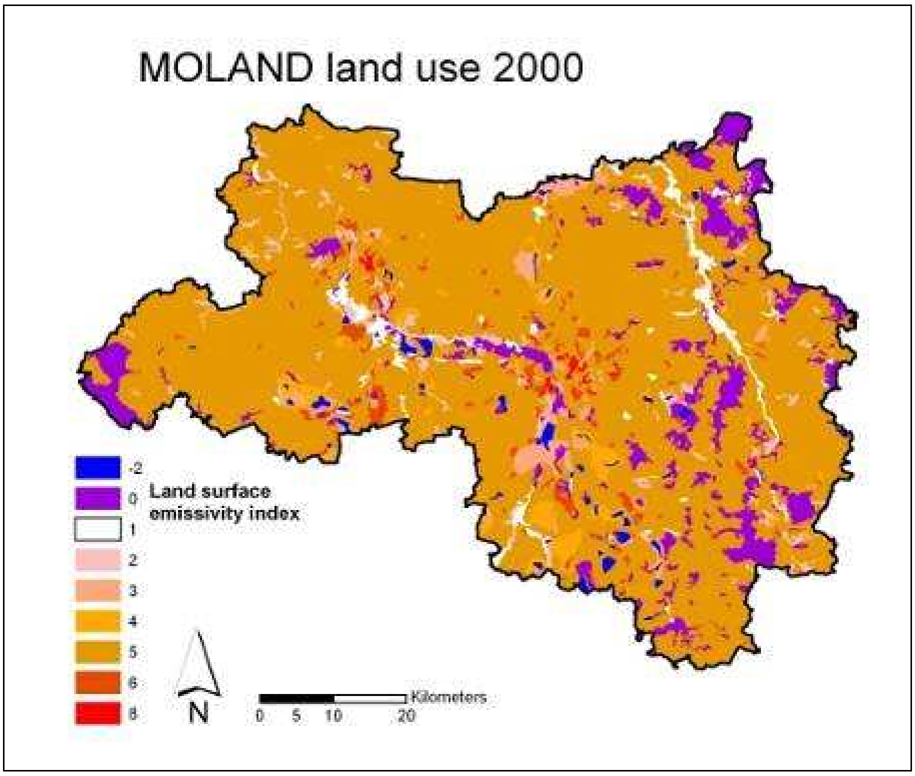

Figure 40: Map of thermal land surface emissivity for the Leipzig case study, year 2000

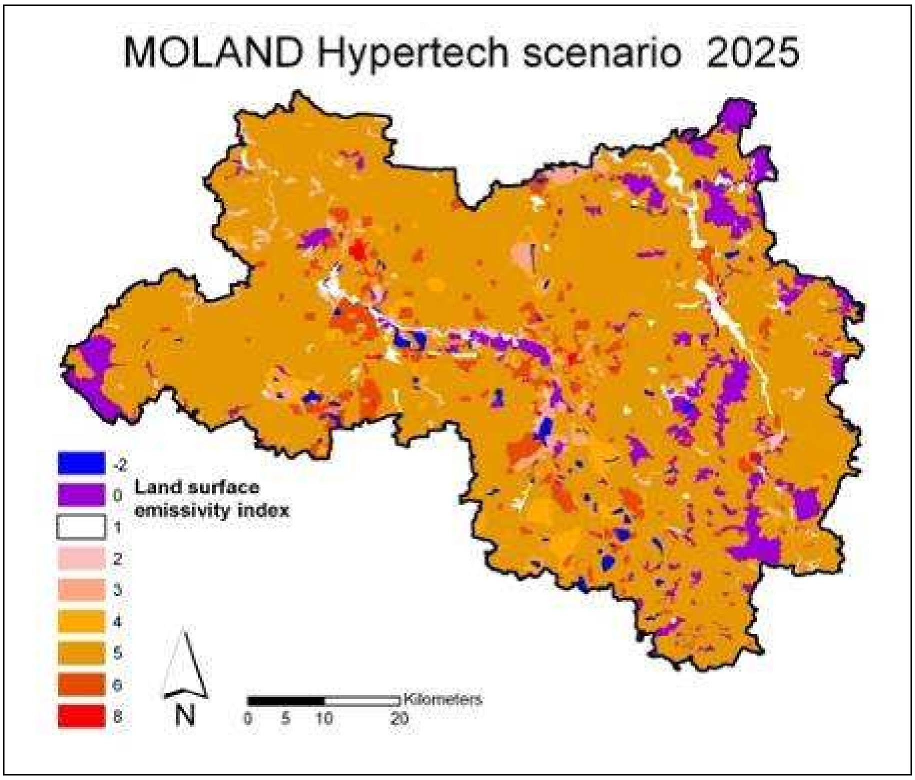

Figure 41: Map of thermal land surface emissivity for the Leipzig case study, MOLAND Hypertech scenario year 2025

Recreation

Definition "Recreation"

The indicator describes the availability of urban recreational green space (supply) compared to the number of residents (demand).

Quantification method

Three different measures to determine the recreation potential have been used. Urban green space (UGS) was taken as a proxy for recreation space:
1. UGS supply: The green space supply was computed using a Geographic Information System (GIS)-selection procedure identifying and extracting all UGS land use types.
2. UGS supply demand per capita: The per capita demand of UGS was determined as the UGS supply of a municipal local district divided by the number of people living there.
3. UGS accessibility: The GIS-based network analysis uses spatial network data in order to calculate distances between points or nodes of the network. We applied the GIS-tool "multiple closest facilities" to determine the distances between population number and UGS.

Significance for rural urban regions

Urban green spaces, urban flora and fauna provide a lot of recreation (plus aesthetic and educational) services to the residents and thus play an important role as determinant of life quality for citizens of urban regions. UGS hold space for recreation, regulate the micro-climate or reduce noise and thus represent a service for man by nature. Given that city regions are 'people places', attempts to preserve nature and ecosystems within city regions can only be successful if they meet the needs and the wishes of the residents.

Exemplary results

Currently, impacts of land use changes were computed solely for the Leipzig case study and selected scenarios, including land uses 1990, 2000, PLUREL scenario Hypertech (year 2025). Results for all other Leipzig scenarios and all other European PLUREL case studies will follow.

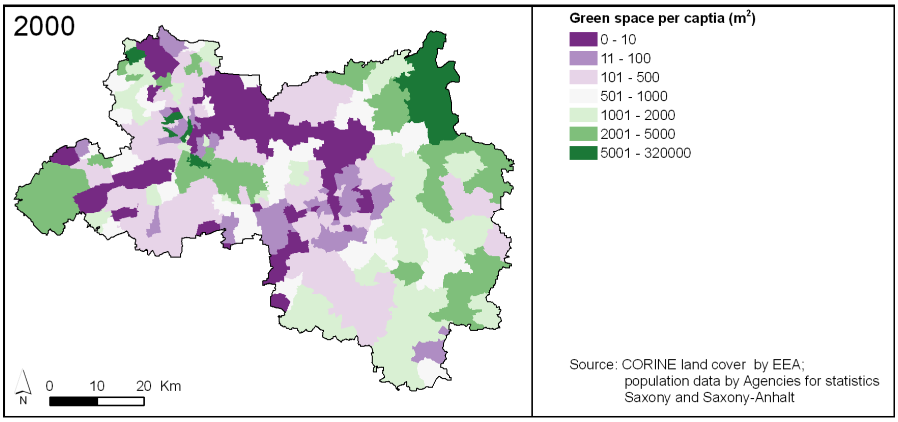

Figure 42: Green space per capita in the Leipzig case study region, year 2000

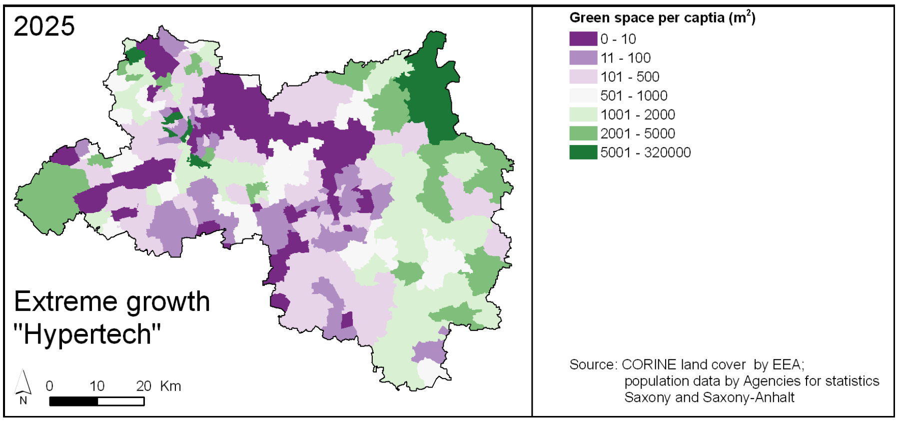

Figure 43: Green space per capita in the Leipzig case study region for the MOLAND hypertech scenario, year 2025

4.4 Social indicators

In order to characterize the social and demographic situations of the investigated regions, we calculated five socio-demographic indicators (population density, settlement population density, household size, housing area per person and mean age) for the resulting rural urban gradients.

The interactions between peri-urban spaces and urban spaces have increased over the past few years. Not only the rising commuting times and increasing number of private cars indicate these new realities which encouraged us to move beyond the simple classification of the urban-rural dichotomy which is no longer adequate for analysing the role of settlement and demographic processes (Champion and Hugo, 2003). Thus, the adoption of a spatial typology that considers the continuum between urban and rural areas seems to be necessary to address the different dynamics of urban development and their demographic interactions fully. In order to achieve this, the urban-rural gradient has been applied. The gradient approach is valuated to be a useful tool in understanding the interrelationships between urban development and urban spatial structure in both ecological and social systems (Alberti et al. 2001, Alberti 2008).
All indicators were calculated with the same method. Nevertheless, we included the description of the methodology in all indicator explanations so that they can also be red and understood individually.

Population density

Definition "population density"

The indicator is defined by number of people per square kilometre.

Quantification method

We calculated the urban-rural gradients of the indicator population density using data from local and regional statistical agencies. For the inner city area, socio-economic data on city district level have been utilised, whereas for the outer city area, data on European local administrative unit 2 level (LAU 2, former NUTS 5) have been applied. The statistical data were then added to shape files of the case study regions showing the considered administrative units in a GIS. Subsequently, 30 concentric buffer rings with an outer radius of 1 to 30km and a diameter of 1km each were created in the GIS around the city centre of each analysed city. To calculate the value of the population density x in a buffer ring *j*, first the ratio *R* of the area of each administrative unit located in buffer ring *j* to the total area *A* of the buffer ring *j* was calculated (1) and then multiplied with the value of the population density *x* in that administrative unit. The results of the product from ratio *R* and population density value *x* of all administrative units in one buffer ring *j* were then summarised to obtain the final medium value of the population density in buffer ring *j* (4):

$$R_{i,j} = \frac{A_{i,j}}{A_j} \qquad (1)$$

$$\tilde{x}_j = \sum_{i=1}^{n} R_{i,j} \cdot x_i \qquad (2)$$

Hence:

$$\tilde{x}_j = \sum_{i=1}^{n} \frac{A_{i,j}}{A_j} x_i \qquad (3)$$

$$\tilde{x}_j = \frac{1}{A_j} \sum_{i=1}^{n} A_{i,j} \cdot x_i \qquad (4)$$

with:

$R_{i,j}$ = ratio of area of administrative unit *i* located in buffer ring *j* to total area of buffer ring *j*
$A_{i,j}$ = area of administrative unit *i* in buffer ring *j*
A_j = total area of buffer ring *j*
x_i = variable value in administrative unit *i*

x_j = variable value in buffer ring j

Significance for rural urban regions

Recent applications of the gradient approach on social systems are mainly restricted on the analysis of population density gradients (Zheng, 1991; Ingram, 1998; Kasanko et al., 2006), which are influenced by the size of the city, centralisation and decentralisation processes, and land rents (Mills, 1972; Ingram, 1998). Nevertheless, population density gradients provide valuable first information about the character of a rural urban region.

Exemplary results

Up to now, rural urban gradients of the population density have been calculated for the case study of Leipzig (years 1995 and 2005), Halle (year 2005), Manchester (years 1991 and 2001) and Warsaw (year 2005). The gradients differ in their steepness and reveal disparities especially in the city centres. Whereas in Warsaw and Halle, the population density is the highest in the centres, this is not the case in Manchester and Leipzig, where the maximal population density can be found at a distance of 3 to 5 km from the city centre. Manchester has a much lower population density in the urban and suburban areas than the other case studies which can be explained by differences in the predominant form of housing (Lichtenberger 1970, Whitehand 2001). In Manchester, 74% of the population lives in single family houses in comparison to 12% in Halle, 11% in Leipzig as 6% in Warsaw (data: www.urbanaudit.org, 2001). Whereas in the other cities, prices per m² living area are lower in apartments than in houses, prices in Manchester are almost the same.

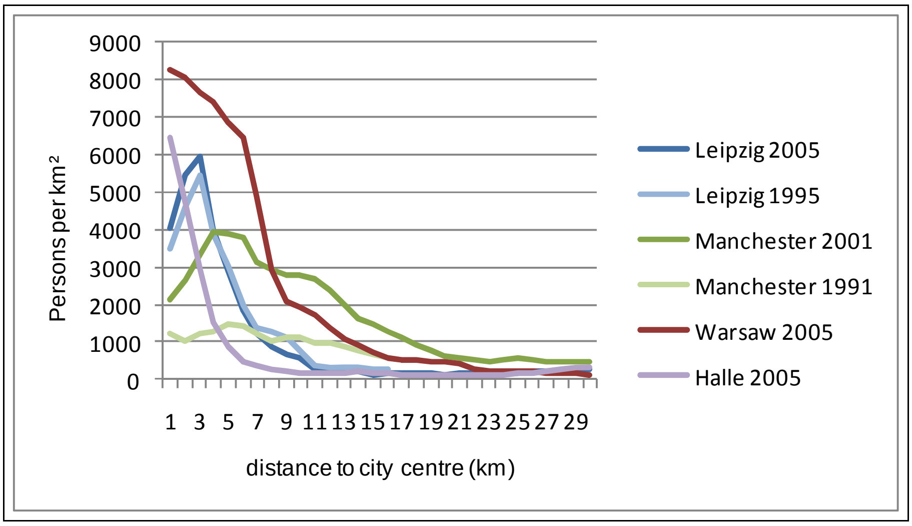

Figure 44: Rural urban gradients of population density for several case study regions

Settlement population density

Definition "settlement population density"

The indicator is defined by the number of people per square kilometre urban fabric.

Quantification method

We calculated the urban-rural gradients of the indicator settlement population density using data from local and regional statistical agencies. First, we derived a gradient of urban fabric area using Corine Land Cover 2000 data (land use classes "continuous urban fabric" and "discontinuous urban fabric") and combined it with a gradient of the total population number. For the inner city area, socio-economic data on city district level have been utilised, whereas for the outer city area, data on European local administrative unit 2 level (LAU 2, former NUTS 5) have been applied. The statistical data were then added to shape files of the case study regions showing the considered administrative units in a GIS. Subsequently, 30 concentric buffer rings with an outer radius of 1 to 30km and a diameter of 1km each were created in the GIS around the city centre of each analysed city. To calculate the value of a variable x in a buffer ring j, first the ratio R of the area of each administrative unit located in buffer ring j to the total area A of the buffer ring j was calculated (1) and then multiplied with the value of variable x in that administrative unit. The results of the product from ratio R and variable value x of all administrative units in one buffer ring j were then summarised to obtain the final medium value of variable x in buffer ring j (4):

$$R_{i,j} = \frac{A_{i,j}}{A_j} \tag{1}$$

$$\tilde{x}_j = \sum_{i=1}^{n} R_{i,j} \cdot x_i \tag{2}$$

Hence:

$$\tilde{x}_j = \sum_{i=1}^{n} \frac{A_{i,j}}{A_j} x_i \tag{3}$$

$$\tilde{x}_j = \frac{1}{A_j} \sum_{i=1}^{n} A_{i,j} \cdot x_i \tag{4}$$

with:

$R_{i,j}$ = ratio of area of administrative unit i located in buffer ring j to total area of buffer ring j

$A_{i,j}$ = area of administrative unit i in buffer ring j

A_j = total area of buffer ring j

x_i = variable value in administrative unit i

x_j = variable value in buffer ring j

Significance for rural urban regions

The settlement population density represents a sustainability indicator related to land use intensity by considering the population number per urban fabric and thus the amount of sealed soil per person. A low settlement population density has negative environmental impacts in several respects. It affects the land and energy resource-efficiency due to a high demand for residential area per person and a high consumption of energy per capita for mobility purposes (Camagni et al. 2002, Newman and Kenworthy 1988 and 1989).

Exemplary results

Up to now, rural urban gradients of the settlement population density have been calculated for the case study of Leipzig (2005), Halle (year 2001), Manchester (year 2001) and Warsaw (year 2001). The settlement population density shows high variability and is not the highest in the city cores in most case studies.

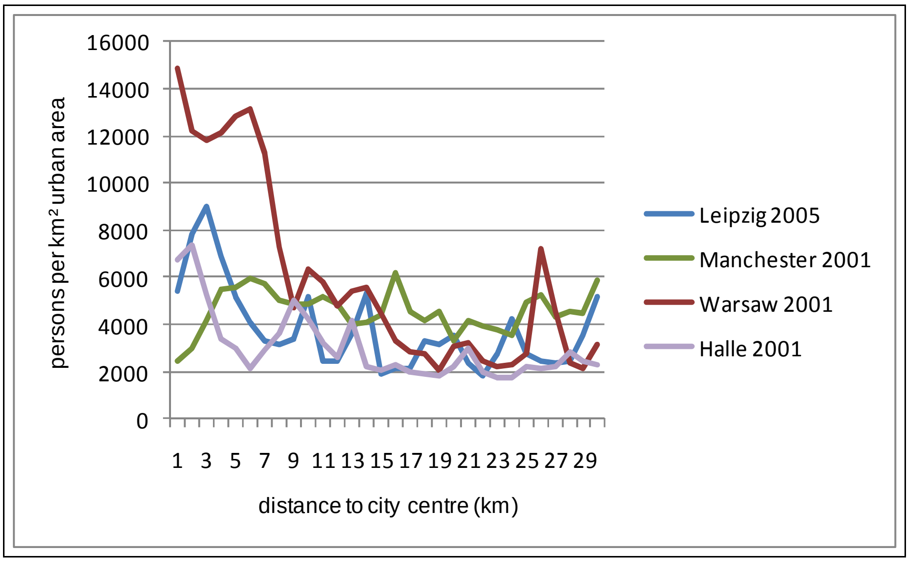

Figure 45: Rural urban gradients of settlement population density for several case study regions

Household size

Definition "household size"

The indicator is defined by the number of people sharing a flat or house.

Quantification method

We calculated the urban-rural gradients of the indicator household size using data from local and regional statistical agencies. For the inner city area, household data on city district level have been utilised, whereas for the outer city area, data on European local administrative unit 2 level (LAU 2, former NUTS 5) have been applied. The statistical data were then added to shape files of the case study regions showing the considered administrative units in a GIS. Subsequently, 30 concentric buffer rings with an outer radius of 1 to 30km and a diameter of 1km each were created in the GIS around the city centre of each analysed city. To calculate the value of a variable x in a buffer ring j, first the ratio R of the area of each administrative unit located in buffer ring j to the total area A of the buffer ring j was calculated (1) and then multiplied with the value of variable x in that administrative unit. The results of the product from ratio R and variable value x of all administrative units in one buffer ring j were then summarised to obtain the final medium value of variable x in buffer ring j (4):

$$R_{i,j} = \frac{A_{i,j}}{A_j} \qquad (1)$$

$$\tilde{x}_j = \sum_{i=1}^{n} R_{i,j} \cdot x_i \qquad (2)$$

Hence:

$$\tilde{x}_j = \sum_{i=1}^{n} \frac{A_{i,j}}{A_j} x_i \qquad (3)$$

$$\tilde{x}_j = \frac{1}{A_j} \sum_{i=1}^{n} A_{i,j} \cdot x_i \qquad (4)$$

with:

$R_{i,j}$ = ratio of area of administrative unit i located in buffer ring j to total area of buffer ring j
$A_{i,j}$ = area of administrative unit i in buffer ring j
A_j = total area of buffer ring j
x_i = variable value in administrative unit i
x_j = variable value in buffer ring j

Significance for rural urban regions

The derivation of housing related urban-rural gradients can provide helpful information for city planners notably against the background that demographic and socioeconomic indicators describing a county as a whole may not be necessarily the same for distinctive urban and rural areas. In European countries, a trend towards smaller household sizes, especially one-person households, can be observed. This lifestyle characteristic, which is still dominant in city centres, in spreading more and more into rural areas. In resource terms, smaller households consume more land and have also lower resource efficiencies per capita than larger households (Williams 2005, Liu et al 2003, Lenzen et al 2004). Thus, the decrease of household sizes is related to higher environmental impacts.

Exemplary results

Up to now, rural urban gradients of the household size have been calculated for the case study of Leipzig (years 1995 and 2005), Halle (year 2005), Manchester (years 1991 and 2001) and Warsaw (year 2005). The results demonstrate that the household size is the lowest in the city centre in all case studies, with exception of Manchester in year 1991. It then increases with distance from the city centre in Warsaw and Manchester, but reaches a maximum in the suburban regions in Halle and Leipzig.

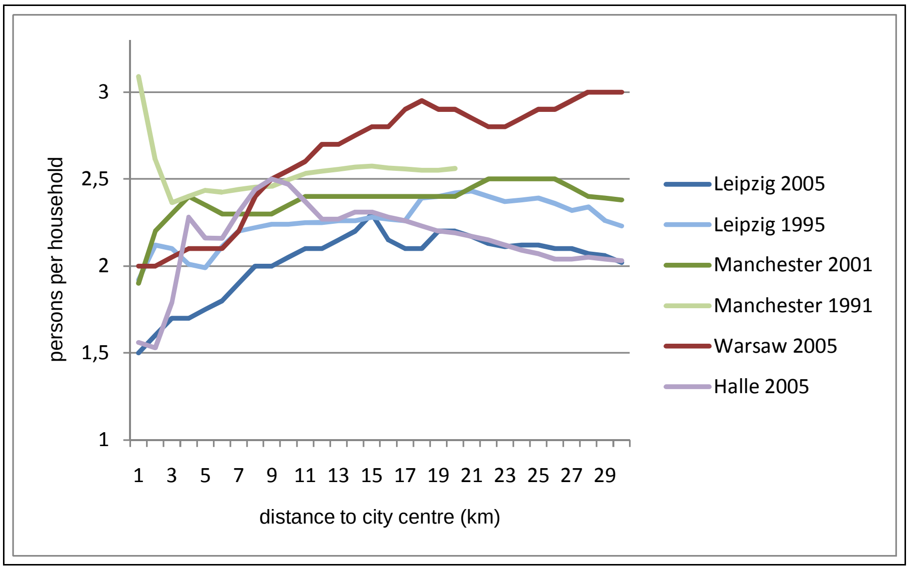

Figure 46: Rural urban gradients of the household size for several case study regions

Housing area per person

Definition "housing area per person"

The indicator is the total housing area in m^2 divided by the total population number.

Quantification method

We calculated the urban-rural gradients of the indicator housing area per person using data from local and regional statistical agencies. For the inner city area, housing area data on city district level have been utilised, whereas for the outer city area, data on European local administrative unit 2 level (LAU 2, former NUTS 5) have been applied. The statistical data were then added to shape files of the case study regions showing the considered administrative units in a GIS. Subsequently, 30 concentric buffer rings with an outer radius of 1 to 30km and a diameter of 1km each were created in the GIS around the city centre of each analysed city. To calculate the value of a variable x in a buffer ring j, first the ratio R of the area of each administrative unit located in buffer ring j to the total area A of the buffer ring j was calculated (1) and then multiplied with the value of variable x in that administrative unit. The results of the product from ratio R and variable value x of all administrative units in one buffer ring j were then summarised to obtain the final medium value of variable x in buffer ring j (4):

$$R_{i,j} = \frac{A_{i,j}}{A_j} \quad (1)$$

$$\tilde{x}_j = \sum_{i=1}^{n} R_{i,j} \cdot x_i \quad (2)$$

Hence:

$$\tilde{x}_j = \sum_{i=1}^{n} \frac{A_{i,j}}{A_j} x_i \quad (3)$$

$$\tilde{x}_j = \frac{1}{A_j} \sum_{i=1}^{n} A_{i,j} \cdot x_i \quad (4)$$

with:

$R_{i,j}$ = ratio of area of administrative unit i located in buffer ring j to total area of buffer ring j
$A_{i,j}$ = area of administrative unit i in buffer ring j
A_j = total area of buffer ring j
x_i = variable value in administrative unit i
x_j = variable value in buffer ring j

Significance for rural urban regions

Similar to the household size, also the housing area per person can be linked to environmental impacts via resource, energy and land consumption (Wilson and Boehland, 2005).

Exemplary results

Up to now, rural urban gradients of housing area indicator have been calculated for the case study of Leipzig (years 1995 and 2005), Halle (year 2005), Manchester (2001) and Warsaw (year 2005). The results reveal that the housing area per person is not necessarily the lowest in the city centres (this is only the case in Warsaw), and seem to be rather linked with the household size than with the distance to the city centre.

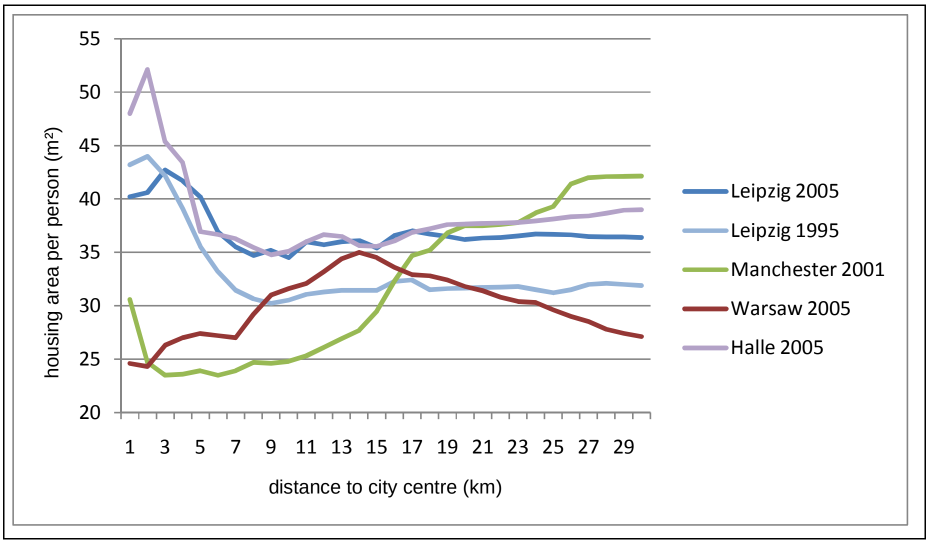

Figure 47: Rural urban gradients of the housing area per person for several case study regions

Mean age

Definition “mean age”

The indicator is defined by the average age level of the population.

Quantification method

We calculated the urban-rural gradients of the indicator mean age using data from local and regional statistical agencies. For the inner city area, age structure data on city district level have been utilised, whereas for the outer city area, data on European local administrative unit 2 level (LAU 2, former NUTS 5) have been applied. The statistical data were then added to shape files of the case study regions showing the considered administrative units in a GIS. Subsequently, 30 concentric buffer rings with an outer radius of 1 to 30km and a diameter of 1km each were created in the GIS around the city centre of each analysed city. To calculate the value of a variable *x* in a buffer ring *j*, first the ratio *R* of the area of each administrative unit located in buffer ring *j* to the total area *A* of the buffer ring *j* was calculated (1) and then multiplied with the value of variable *x* in that administrative unit. The results of the product from ratio *R* and variable value *x* of all administrative units in one buffer ring *j* were then summarised to obtain the final medium value of variable *x* in buffer ring *j* (4):

$$R_{i,j} = \frac{A_{i,j}}{A_j} \qquad (1)$$

$$\tilde{x}_j = \sum_{i=1}^{n} R_{i,j} \cdot x_i \qquad (2)$$

Hence:

$$\tilde{x}_j = \sum_{i=1}^{n} \frac{A_{i,j}}{A_j} x_i \qquad (3)$$

$$\tilde{x}_j = \frac{1}{A_j} \sum_{i=1}^{n} A_{i,j} \cdot x_i \qquad (4)$$

with:

$R_{i,j}$ = ratio of area of administrative unit *i* located in buffer ring *j* to total area of buffer ring *j*

$A_{i,j}$ = area of administrative unit *i* in buffer ring *j*

A_j = total area of buffer ring *j*

x_i = variable value in administrative unit *i*

x_j = variable value in buffer ring *j*

Significance for rural urban regions

The changing age structure is an important aspect of demographic change and is influenced by natural population growth as well as migration patterns. Thus, the rural urban distribution of the age structure gives hints about the characteristic of both of these drivers in rural urban regions. Different age groups have different requirements for the social and traffic infrastructure. Thus, information about their distribution are very helpful for city planners.

Exemplary results

Up to now, rural urban gradients of the mean age indicator have been calculated for the case study of Leipzig (years 1995 and 2005), Halle (year 2005), Manchester (years 1991 and 2001) and Warsaw (year 2005). They elucidate the fact that people living in the city centres are generally younger, although this is not the case in Warsaw.

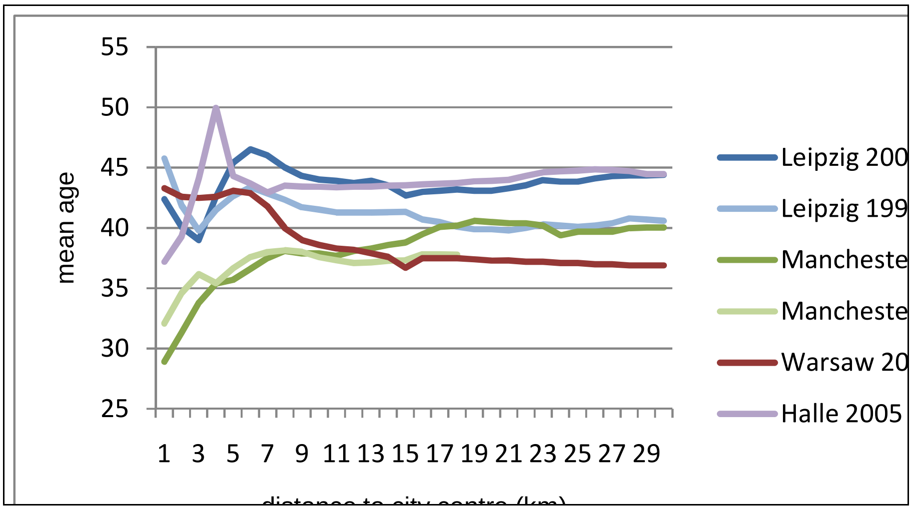

Figure 48: Rural urban gradients of the mean age per person for several case study regions

Indicators in development

Besides the described variables, further parameters are investigated by ESA to describe the preferences of people in housing decisions. The investigated attributes are:

- Air quality
- Access to public green spaces
- Availability and access to public transport
- Availability of shopping facilities
- Noise pollution
- Area safety and security
- House or flat suitability
- Waste collection

In this context, quality of life is associated with the affordances people have in the place where they live. Thus, to understand how land use change affects individual QoL residential choice is used as a means of establishing what kinds of changes affect in what way. The respective conjoint analysis will also be used to determine the significance of the mentioned variables to indicate the consequences of land use change in rural-urban regions. The respective documentation will be provided in another deliverable paper.

4.5 Economic indicators

Economic variables function as drivers as well as impacts for the situation of rural-urban regions. Two indicators from this group have been quantified and tested: commuting distances and unemployment rate. Further variables are under development.

Commuting distance

Definition "commuting distance"

The indicator describes the proportion of employees commuting to the Leipzig core area in a 45km radius around the city as well as the probability of people to commute to the core area in a rural urban gradient.

Quantification method

The gradient approach was applied to measure the commuting pattern of in-commuting to the centre from surrounding areas. For this, statistical commuting pattern data (origin-destination data) as well as employment data on municipality level in a 45km radius around Leipzig for the two time steps 2000 and 2008 were applied.

Significance for rural urban regions

Suburbanisation and urban sprawl, two common phenomena in European rural urban regions, lead to an increased average commuting distance and thereby to a rise of vehicle-kilometres travelled. Especially in urban regions, where particulate matter resulting from traffic emissions is one of the major environmental problems, this issue has a primary significance.

Exemplary results

The commuting catchment area of Leipzig increased from 2000 to 2008 (see Figures 50 and 51). Also the commuting probability gradients show an increased probability of commuting to the centre from the suburban and rural hinterland.

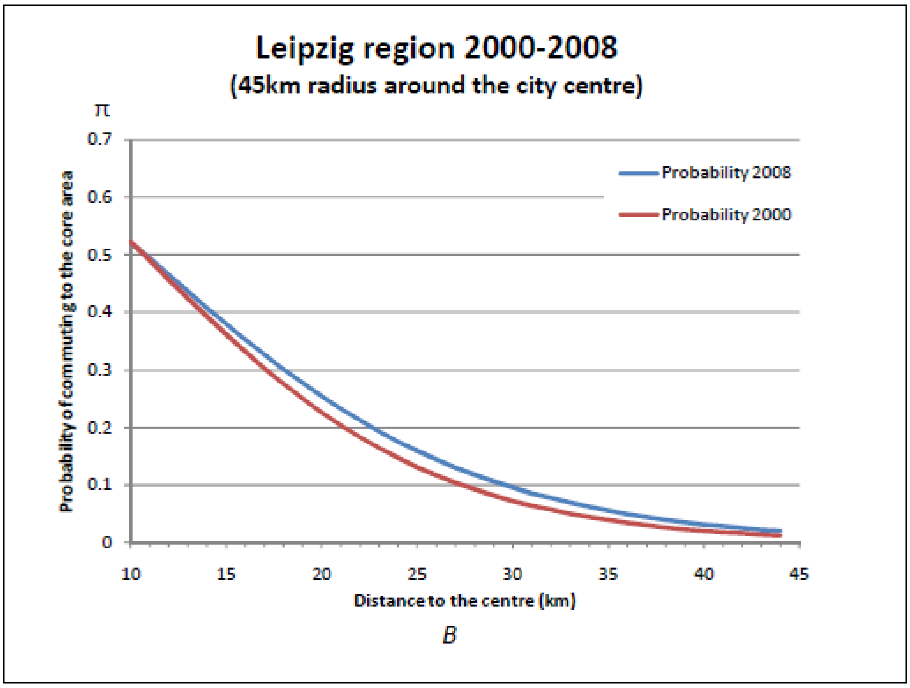

Figure 49: Rural urban gradients of the probability to commute to the Leipzig core area for the two time steps 2000 and 2008

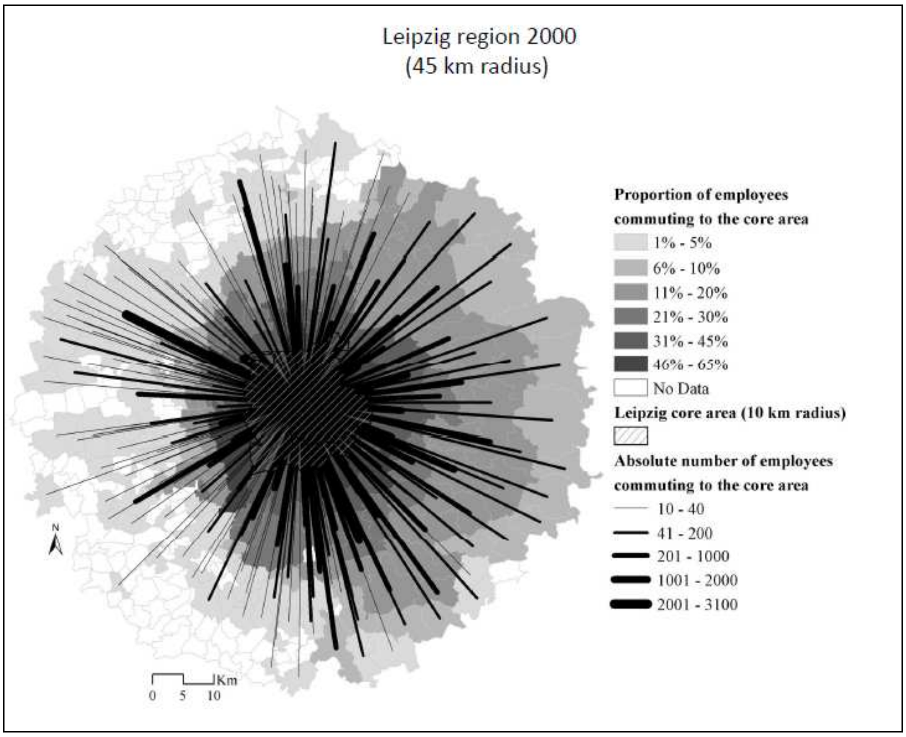

Figure 50: Proportion of employees as well as absolute number of employees commuting to the core area of Leipzig at municipality level for the year 2000.

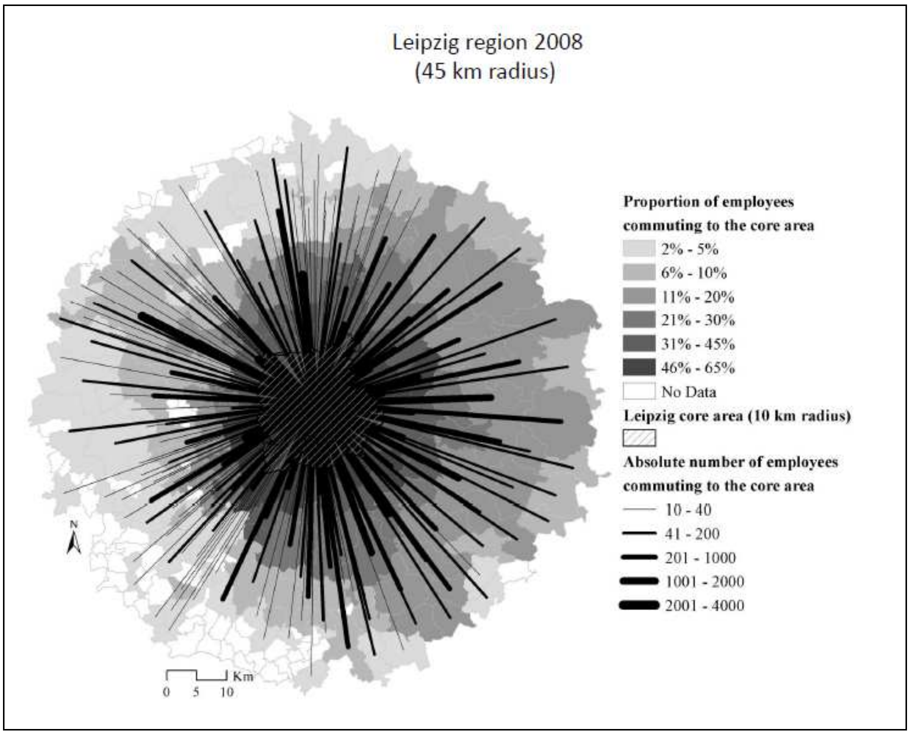

Figure 51: Proportion of employees as well as absolute number of employees commuting to the core area of Leipzig at municipality level for the year 2008.

Unemployment rate

Definition "unemployment rate"

The indicator is defined by the unemployed persons as percentage of the total working population.

Quantification method

We calculated the urban-rural gradients of the indicator unemployment rate using data from local and regional statistical agencies. For the inner city area, unemployment data on city district level have been utilised, whereas for the outer city area, data on European local administrative unit 2 level (LAU 2, former NUTS 5) have been applied. The statistical data were then added to shape files of the case study regions showing the considered administrative units in a GIS. Subsequently, 30 concentric buffer rings with an outer radius of 1 to 30km and a diameter of 1km each were created in the GIS around the city centre of each analysed city. To calculate the value of a variable *x* in a buffer ring *j*, first the ratio *R* of the area of each administrative unit located in buffer ring *j* to the total area *A* of the buffer ring *j* was calculated (1) and then multiplied with the value of variable *x* in that administrative unit. The results of the product from ratio *R* and variable value *x* of all administrative units in one buffer ring *j* were then summarised to obtain the final medium value of variable *x* in buffer ring *j* (4):

$$R_{i,j} = \frac{A_{i,j}}{A_j} \qquad (1)$$

$$\tilde{x}_j = \sum_{i=1}^{n} R_{i,j} \cdot x_i \qquad (2)$$

Hence:

$$\tilde{x}_j = \sum_{i=1}^{n} \frac{A_{i,j}}{A_j} x_i \qquad (3)$$

$$\tilde{x}_j = \frac{1}{A_j} \sum_{i=1}^{n} A_{i,j} \cdot x_i \qquad (4)$$

with:

$R_{i,j}$ = ratio of area of administrative unit *i* located in buffer ring *j* to total area of buffer ring *j*
$A_{i,j}$ = area of administrative unit *i* in buffer ring *j*
A_j = total area of buffer ring *j*
x_i = variable value in administrative unit *i*
x_j = variable value in buffer ring *j*

Significance for rural urban regions

The unemployment rate is an important socio-economic indicator and its rural urban distribution reveals basic differences between urban, suburban and rural regions.

Exemplary results

Up to now, rural urban gradients of the unemployment rate have been calculated for the case study of Leipzig (years 1995 and 2005), Halle (year 2005), Manchester (years 1991 and 2001) and Warsaw (year 2005). The results elucidate the fact that people living in the city centres are generally in a less favourable economic situation, although this is not the case in Warsaw. Especially in Manchester, strong changes can be observed between the two time steps 1991 and 2001.

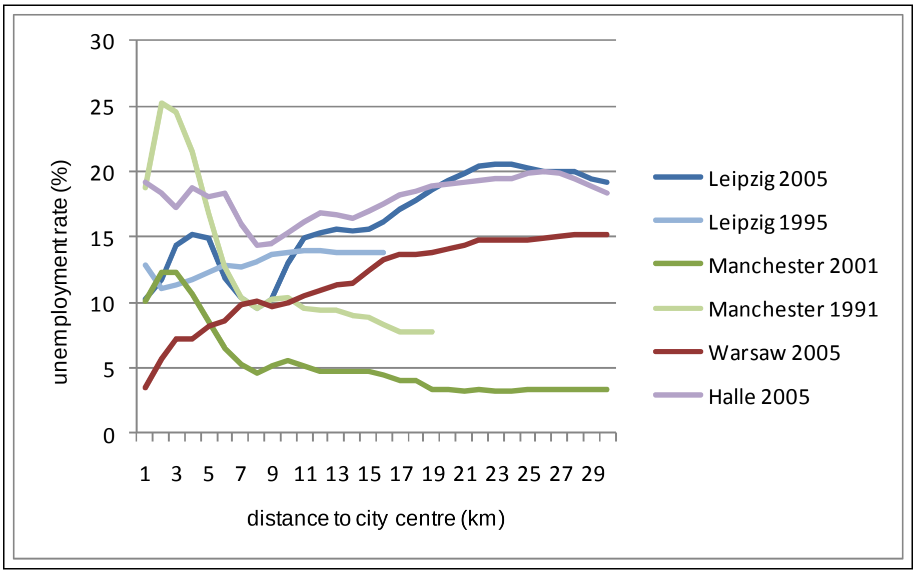

Figure 52: Rural urban gradients of the unemployment rate for several case study regions

Indicators in development

Additional features of the economic circumstances in rural-urban regions are recently worked out by UBATH. They are planned to comprise of:

- GDP
- External costs green space
- Costs carbon stock
- Costs air pollution

The results of tests with these indicators can not be presented due to a delay which has been caused by changes in the project structure (shift of responsibilities from ZEW to UBATH).

5. Future Work

During the last project phase until the end of 2010, several tasks have to be carried out. All of them are basing on the interim results which have been described in this report. The major working steps will be:

Integrating the Indicators and the scenario results into the PLUREL tools

The main PLUREL tools are the PLUREL XPLORER and an integrated Impact Analysis Tool (iIAT region and iIAT Europe) which will be integrated into the XPLORER. The PLUREL XPLORER will be an online tool containing all PLUREL outputs, data and products and thereby offering the possibility to browse the evidence of peri-urban land use relationships and sustainability effects. The indicator results will be represented in the PLUREL XPLORER by a factsheet describing the indicator framework as well as by individual factsheets for each key indicator. These factsheets will contain information about the indicator definition, the quantification method, final results in form of maps and graphs and a discussion of these results.

The integrated Impact Analysis Tool offers the possibility to the end users to assess environmental, social and economic impacts of land use change scenarios in rural urban regions at European and case study level. It allows the comparison of land use change impacts on the sustainability indicators between different case studies and scenarios. The indicator results will directly be displayed in form of spider diagrams for different land use scenarios and can then be evaluated by the user as “sustainable” or “non-sustainable” and compared with his own target values. Thus, the final quantification results of the key indicators described in this report for the years 1990, 2000 and different MOLAND scenarios as well as for different case studies will be incorporated into the iIAT region.

Completing the ecological Indicators - Ecosystem Integrity

Furthermore three integrity indicators will be developed in qualification theses at the Ecology Centre of Kiel University. Those are:

- Landscape heterogeneity which is analyzed on the base of several landscape metrics in case study areas,
- Net primary production which will be derived from time-series of satellite images, and
- CO_2 production (to be assessed mainly based on traffic emissions, industry emissions and housing) and carbon sequestration potential as a function of land cover and soil conditions.

Completing Land Use Indicators - Landscape Metrics

To characterize the investigated landscape patterns in the case study areas, the produced maps are analysed on the base of several landscape metrics approaches. In this work about 30 different indicators are investigated and will be strongly condensed. The resulting most meaningful variable which has the highest degree of indication will be selected for an additional description of the overall landscape pattern in the rural-urban region.

Applying the "Fast RUR Land Cover Assessment"

In the recent stage, the quantification of the ecological integrity indicators as well as the ecosystem service indicators is based on comprehensive quantitative interpretations of statistics and intensive modelling works. As these procedures are rather complicated, a first version of a “Fast RUR Land Cover Assessment” has been developed. It is based on the matrix in Table 12, which shows a qualitative valuation of the potentials of different land cover classes to provide ecosystem services (for detailed information see Burkhard et al. 2009). This simple “translation model” will be applied in the PLUREL case study areas. The results of both approaches will be compared, and thus the focal demands for improvement of the assessment matrix will be determined. After the respective improvement of the qualitative system it will be applied in all case study regions and the methodology will be provided in the PLUREL toolbox.

Table 12: Basic matrix of the potentials to provide ecosystem services and integrity values for the different CORINE land cover classes; after Burkhard et al. (2009). While on the vertical axis all Corine land cover types are listed, the horizontal axis shows ecosystem services and integrity variables. Indicated by the numbers 0-5 and the colours, the respective support mechanisms for service provision are classified. The matrix can be linked to GIS to produce qualitative maps. Recently the classification scheme is being improved, also referring to geomorphological and soil features.

	Ecological Integrity Σ	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy Capture (Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	Provisioning services Σ	Crops	Livestock	Fodder	Capture Fisheries	Acquaculture	Wild Foods	Timber	Wood Fuel	Energy (Biomass)	Biochemicals / Medicine	Freshwater	Regulating services Σ	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	Cultural services Σ	Recreation& Aesthetic Values	Intrinsic Value of Biodiversity
Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discontinuous urban fabric	7	1	1	1	1	1	1	1	3	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial or commercial units	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Road and rail networks	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port areas	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	1	1	0
Airports	7	1	1	1	1	1	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mineral extraction sites	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dump sites	8	2	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction sites	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green urban areas	18	3	3	2	1	4	3	2	2	0	0	0	0	0	1	0	1	0	0	0	11	2	1	0	2	1	2	1	1	1	3	3	0
Sport and leasure facilities	16	2	2	2	1	4	3	2	0	0	0	0	0	0	0	0	0	0	0	0	9	1	1	0	2	1	1	1	1	1	5	5	0
Non-irrigated arable land	22	3	2	3	4	5	1	4	21	5	5	5	0	0	0	0	0	5	1	0	5	2	1	1	1	0	0	0	0	0	1	1	0
Permanently irrigated land	21	3	2	5	2	5	1	3	18	5	5	2	0	0	0	0	0	5	1	0	5	3	1	1	0	0	0	0	0	0	1	1	0
Ricefields	20	3	2	5	1	5	1	3	7	5	0	2	0	0	0	0	0	0	0	0	4	2	0	0	2	0	0	0	0	0	1	1	0
Vineyards	14	3	2	3	1	3	0	2	5	4	0	0	0	0	0	0	1	0	0	0	3	1	1	0	1	0	0	0	0	0	5	5	0
Fruit trees and berries	21	4	3	4	2	3	2	3	13	5	0	0	0	0	0	4	4	0	0	0	19	2	2	2	2	2	2	1	1	5	5	5	0
Olive groves	17	3	2	3	2	3	1	3	12	4	0	0	0	0	0	4	4	0	0	0	7	1	1	0	1	1	1	1	1	0	5	5	0
Pastures	24	2	2	4	5	5	2	4	10	0	5	5	0	0	0	0	0	0	0	0	8	1	1	1	1	0	4	0	0	0	3	3	0
Annual and permanent crops	18	2	2	3	2	4	2	3	20	5	5	5	0	0	0	0	0	5	1	0	7	2	1	1	1	1	1	0	0	0	1	1	0
Complex cultivation patterns	20	4	3	3	2	4	1	3	9	4	0	3	0	0	0	0	0	0	2	0	5	2	1	1	1	0	0	0	0	0	2	2	0
Agriculture& natural vegetation	19	3	3	3	2	3	2	3	21	3	3	2	0	0	3	3	3	3	1	0	13	3	2	1	2	1	3	0	1	0	5	2	3
Agro-forestry areas	27	4	4	4	3	4	4	4	14	3	3	2	0	0	0	3	3	0	0	0	13	2	1	1	1	1	2	1	1	3	3	3	0
Broad-leaved forest	31	3	4	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Coniferous forest	30	3	4	4	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Mixed forest	32	3	5	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Natural grassland	30	3	5	4	4	4	5	5	5	0	3	0	0	0	2	0	0	0	0	0	22	2	3	1	1	0	5	5	5	0	6	3	3
Moors and heathland	30	3	4	4	5	4	5	5	10	0	2	0	0	0	1	0	2	5	0	0	20	4	3	2	2	0	0	3	4	2	10	5	5
Sclerophyllous vegetation	21	3	4	2	3	3	4	2	8	0	2	0	0	0	1	0	2	0	3	0	7	2	1	1	1	0	0	0	0	2	6	2	4
Transitional woodland shrub	21	3	4	2	3	3	4	2	5	0	2	0	0	0	1	0	2	0	0	0	3	1	0	0	0	0	0	0	0	2	4	2	2
Beaches, dunes and sand plains	10	3	3	1	1	1	0	1	2	0	0	0	0	0	0	0	0	2	0	0	6	0	0	5	1	0	0	0	0	0	7	5	2
Bare rock	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	1	0	0	0	1	0	4	4	0
Sparsely vegetated areas	9	2	3	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0
Burnt areas	6	2	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Glaciers and perpetual snow	3	2	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	5	10	3	3	0	4	0	0	0	0	0	5	5	0
Inland marshes	25	3	2	4	4	4	3	5	7	0	2	5	0	0	0	0	0	0	0	0	14	2	2	4	2	0	0	4	0	0	0	0	0
Peatbogs	29	3	4	4	4	4	5	5	5	0	0	0	0	0	0	0	0	5	0	0	24	4	5	3	3	0	0	3	4	2	8	4	4
Salt marshes	23	2	3	4	3	3	3	5	2	0	2	0	0	0	0	0	0	0	0	0	8	1	0	5	0	0	0	2	0	0	3	3	0
Salines	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	2	2	0
Intertidal flats	13	2	3	0	2	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	5	0	0	0	1	0	0	4	4	0
Water courses	18	4	4	0	3	3	3	1	12	0	0	0	3	0	4	0	0	0	0	5	10	1	0	2	1	0	0	3	3	0	10	5	5
Water bodies	23	4	4	0	4	4	3	4	12	0	0	0	3	0	4	0	0	0	0	5	7	2	1	1	2	0	0	1	0	0	9	5	4
Coastal lagoons	25	4	4	0	5	5	3	4	16	0	0	0	4	5	4	0	0	3	0	0	5	1	0	4	0	0	0	0	0	0	9	5	4
Estuaries	21	3	3	0	5	5	3	2	17	0	0	0	5	5	4	0	0	3	0	0	9	0	0	3	0	0	0	3	3	0	7	4	3
Sea and ocean	15	2	2	0	3	3	4	1	11	0	0	1	5	5	0	0	0	0	0	0	13	3	5	0	0	0	0	5	0	0	6	4	2

Elaborating the Social and Economic Indicators

In parallel to the tasks listed above, the additional social and economic indicators have to be developed and applied. The results of these steps will be documented by the responsible institutions.

References

Alberti, M. (2008) Advances in urban ecology: integrating humans and ecological processes in urban ecosystems. Springer, New York

Alberti, M., Botsford, E., Cohen, A. (2001) Quantifying the urban gradient: linking urban planning and ecology. In: Marzluff, J.M., Bowman, R., Donnelly, R. (eds): Avian ecology and conservation in an urbanizing world. Kluwer Academic

Austin, M.P. (1987) Models for the analysis of species' response to environmental gradients, Vegetatio 69:35-45

Ayensu E., Claasen DV., Collins M., Dearing A., Fresco L., Gadgil M., Gitay H., Glaser G., Lohn CL., Krebs J., Lenton R., Lubchenco L., McNeely JA., Mooney HA., Pinstrup-Andersen P., Ramos M., Raven P., Reid WV., Samper C., Sarukhan J., Schei P., Tundisi JG., Watson RT., Xu GH., Zakri AH. (1999) Ecology – International ecosystem assessment, Science 286, 685-686

Baker, L.A., Hope, D., Xu, Y., Edmonds, J., Lauver, L. (2001) Nitrogen Balance for the Central Arizona-Phoenix (CAP) Ecosystem, Ecosystems 4: 582-602

Barkmann, J. (2002) Modellierung und Indikation nachhaltiger Landschaftsentwicklung – Beiträge zu den Grundlagen angewandter Ökosystemforschung. Diss. University of Kiel

Barkmann, J., Baumann, R., Meyer, U., Müller, F., Windhorst, W. (2001): Ökologische Integrität: Risikovorsorge im Nachhaltigen Landschaftsmanagement. *Gaia* 10/2, 97-108

BBR (2004) Zwischennutzung und neue Freiflachen, stadtische Lebensraume der Zukunft, Projekt des Forschungsprogramms der „Projektplanung Aufbau Ost" des Bundesministeriums fur Verkehr, Bau- und Wohnungswesens und des Bundesamtes fur Bauwesen und Raumordnung, Berlin

Blair, R. (2004) The effects of urban sprawl on birds at multiple levels of biological organisation, Ecology and Society, 9(5)

Bolund, P., Hunhammar, S. (1999) Ecosystem services in urban areas, Ecological Economics 29: 293-301

Bossel, H. (1998) Ecological orientors: Emergence of basic orientors in evolutionary self-organization. In: Müller, F. and Leupelt, M. (1998) Eco targets, goal functions and orientors. Berlin, Heidelberg, New York. 19-33

Bossel, H. (2000) Sustainability: Application of Systems Theoretical Aspects to Societal Development. In: Jørgensen, S.E., Müller, F. (eds) Handbook of ecosystem theories and management, Boca Raton - London - New York - Washington DC, 519-536

Boyd, J. and H.S. Banzhaf (2006) "What Are Ecosystem Services?," Discussion Papers dp-06-02, Resources For the Future.

Burkhard, B. (2004) Ecological Assessment of the Reindeer Husbandry System in Northern Finland, EcoSys Beitrage zur Okosystemforschung, Bd. 43

Burkhard, B. and Müller, F. (2008) Indicating ecosystem health and integrity. In: Denhardt, A. & U. Petschow (Eds.): Sustainability in River Basins – A Question of Governance. Ökom Verlag München. S. 35-57.

Burkhard, B., F. Müller, F. Kroll and W. Windhorst (2009): Landscapes' Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. In: Landscape Online, Edition 15/2009; DOI: 10.3097/LO.200915

Buttner, T. (2006) Demographischer Wandel und regionale Arbeitsmarkte, In: Gans, P., Schmitz-Veltin, A. (eds.) Demographische Trends in Deutschland, Folgen für Stadte und Regionen, Akademie fur Raumforschung und Landesplanung, 226, 54-64

Camagni, R., Gibelli, M.C., Rigamonti, P. 2002: Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion, *Ecological Economics* 40, pp. 199-216

Champion, T., Hugo, G., Lattes, A. (2003) Towards a new conceptualization of settlement for demography; beyond the urban/rural dichotomy. Population and Development Review 29, 277-297.

Clark-Thorne S.T., Yapp, C.J. (2003) Stable carbon isotope constraints on mixing and mass balance of CO2 in an urban atmosphere: Dallas metropolitan area, Texas, USA, Appl. Geochem, 18:75-95

Clergeau, O., Savard, J.P.L., Mennechez, G., Falardeau, G. (1998) Bird abundance and diversity along an urban-rural gradient: A comparative study between two cities on different continents, Condor 100(3), 413-425

Costanza R, D'Arge R, de Groot RS, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of world's ecosystem services and natural capital. *Nature* 387, 253-260

Crabbé P, Holland A, Ryszkowski L, Westra L (2000) Implementing ecological integrity. Kluwer, Dortrecht

Dale, V.H. and Beyeler, S.C. (2001) Challenges in the development and use of ecological indicators. Ecological Indicators 1: 3-10.

Daily, GC, Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D., and Woodwell, G.M. (1997) Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems Issues in Ecology [Issues Ecol.]. Vol. 1, no. 2, pp. 1-18. 1997.

Decker EH, Elliott S, Smith FA, Blake DR, Rowland FS (2000) Energy and Material Flow through the urban ecosystem, Annu. Rev. Energy Environ. 25: 685-740

De Groot RS (1992) Functions of nature: evaluation of nature in environmental planning, management and decision making. Groningen

Dierssen K (2000) Ecosystems as states of ecological successions. In: Jørgensen SE, Müller F (eds.) Handbook of ecosystem theories and management. Boca Raton, 427-445

EEA (1994) Corine Land Cover report. http://www.eea.europa.eu/publications/COR0-landcover (Date: 1.12.2009)

EEA (1995) Europe's Environment: the Dobris Assessment. European Environmental Agency, Copenhagen

EEA (2006) Urban Sprawl in Europe, The ignored challenge, EEA report No. 10/2006

Faerge, J., Magid, J., Penning de Vries, F.W.T. (2001) Urban nutrient balance for Bangkok, Ecological Modelling 139: 63-74

Fath, B., Patten, B.C. (1998) Network orientors: A utility goal function based on network synergism. In: Müller, F., Leupelt, M. (1998) Eco targets, goal functions and orientors. Berlin, Heidelberg, New York, 161-176

Fath, B., Patten, B.C. (2000) Ecosystem theory: Network environ analysis. In : Jørgensen, S.E., Müller, F. (eds.) Handbook of ecosystem theories and management. Boca Raton, 345-360

Forbes, B.C., Bölter, M., Müller-Wille, L., Hukkinen, J., Müller, F., Gunslay, N., Konstantinov, Y. (eds) (2006) Reindeer Management in northernmost Europe. Ecological Studies 184. Springer

Gundersson, L.H., Holling, C.S. (eds. 2002) Panarchy. Washington D.C.

Haase, D. (2009) Effects of urbanization on the water balance – A long-term trajectory, Environmental Impact Assessment Review 29: 211-219

Haase, D., Nuissl, H. (2007) Does urban sprawl drive changes in the water balance and policy? The case of Leipzig (Germany) 1870-2003, Landscape and Urban Planning 80(1-2): 1-13

Heiland S., Regener, M., Stutzriemer, S. (2005) Auswirkungen des demographischen Wandels auf Umwelt und Naturschutz, RuR 3/2005

Holling, C.S. (1986) The resilience of terrestrial ecosystems: local surprise and global change. In: Clark, W.M., Munn, R.E. (eds.) Sustainable development of the biosphere., Oxford, 292-320.

Holten-Andersen, J., Paalby, H., Christensen, N., Wier, M., Andersen, F.M. (1995) Recommendations on strategies for integrated assessment of broad environmental problems. Report submitted to the European Environment Agency (EEA) by the National Environmental Research Institute (NERI), Denmark

Ingram, G.K. (1998) Patterns of Metropolitan Development: What have we learned? Urban Studies 35(7): 1019-1035

Jørgensen, S.E. (1996) Integration of ecosystem theories – a pattern, Dortrecht

Jørgensen, S.E. (2000) The tentative fourths law of thermodynamics. In: Jørgensen, S.E., Müller, F. (eds.) Handbook of ecosystem theories and management. Boca Raton, 161-176

Jørgensen, S.E., Müller, F. (2000) Ecological orientors – a path to environmental applications of ecosystem theories. In: Jørgensen, S.E., Müller, F. (eds.) Handbook of ecosystem theories and management. Boca Raton, 561-576

Karr, J.R., Dudley, D.R. (1981) Assessment of biotic integrity using fish communities. *Fisheries* 6, 21-27

Kasanko, M., Barredo, J.I., Lavalle, C., McCormick, N., Demicheli, L., Sagris, V., Brezger, A. (2006) Are European cities becoming dispersed? A comparative analysis of 15 European urban areas, Landscape and Urban Planning 77 (2006) 111-130

Kay, J.J. (2000) Ecosystems as self-organised holarchic open systems: Narratives and the second law of thermodynamics. In: Jørgensen, S.E., Müller, F. (eds.) Handbook of ecosystem theories and management. Boca Raton, 135-160

Kaul J.A., Reins, C. (2000) Abschlussbericht des Sensitivitatsanalyse zu einem integrierten Kustenschutzkonzept fur die Kustenniederung Timmendorfer Strand / Scharbeutz im Auftrag vom Ministerium fur landliche Raume, Landesplanung, Landwirtschaft und Tourismus des Landes Schleswig-Holstein, Kiel

Kennedy, C., Cuddihy, J., Engel-Yan, J. (2007) The Changing Metabolism of Cities, Journal of Industrial Ecology 11(2): 43-59

Kinzig, A.P., Warren, P., Martin, C., Hope, D., Katti, M. (2005) The Effetcs of Human Socioeconomic Status and Cultural Characteristics on Urban Patterns of Biodiversity, Ecology and Society 10(1)

Kocks, M., 2007: Konsequenzen des demographischen Wandels fur die Infrastruktur im landlichen Raum, Geographische Rundschau, 59 (2) 24-31

Koerner, B., Klopatek, J. (2002) Anthropogenic and natural CO_2 emission sources in an arid urban environment. Environ Pollut 116: 45-51

Leopold, A. (1944/1991) Conservation: In whole or in part? In: Flader, S., Callicott, J.B. (1991) The river of the mother of God and other essays by Aldo Leopold. University of Wisconsin Press, Madison, 310-319

Luck, M, Wu, J. (2002) A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA, Landscape Ecology 17: 327-339

McDonnell, M.J., Pickett, S.T.A. (1990) Ecosystem Structure and Function along Urban-Rural Gradients: An Unexploited Opportunity for Ecology, Ecology 71(4): 1232-1237

McDonnell, M.J., Pickett, S.T.A., Groffman, P., Bohlen, P., Pouyat, R.V., Zipperer, W.C., Parmelee, R.W., Carreiro, M.M., Medley, K. (1997): Ecosystem processes along an urban-to-rural gradient, In: Marzluff, J.M., Shulenberger, E., Endlicher, W., Alberti, M., Bradley, G., Ryan, C., ZumBrunnen, C., Simon, U. (eds.) Urban Ecology, pp.299-314, Springer

Melles, S.J. (2005): Urban Bird Diversity as an Indicator of Human Social Diversity and Economic Inequality an Vancouver, British Columbia, Urban Habitats 3(1), 25-47

Millenium Ecosystem Assessment (2005). Ecosystems and Human Well-being. A Framework for Assessment. Island Press: Washington. 2005

Mills, E.S. (1972) Urban Economics. Glenview, II: Scott-Foreman.

Müller, F. (1997) State of the art in ecosystem theory. *Ecological Modelling* 100, 135-161

Müller, F. (2004) Ecosystem indicators fort he integrated management of landscape health and integrity, In: Jørgensen, S.E., Costanza, R., Fu-Liu, X. (eds) Ecological indicators for assessment of ecosystem health. Taylor and Francis, Boca Raton, 277-303

Müller, F. (2005) Indicating ecosystem and landscape organisation. *Ecological Indicators* 5, 280-294

Müller, F., Hoffmann-Kroll, R., Wiggering, H. (2000) Indicating ecosystem integrity - from ecosystem theories to eco targets, models, indicators and variables, *Ecological Modelling*, 13-23

Müller, F., Leupelt, M. (1998) Eco targets, goal functions and orientors. Berlin, Heidelberg, New York

Niemeijer, D. and R.R. de Groot (2008) A conceptual framework for selecting environmental indicator sets, Ecological Indicators, Vol. 8/1, 14-25

Newman. P.W.G, Kenworthy, J.R. 1988: The Transport Energy Trade-Off: Fuel-Efficienct Traffic versus Fuel-Efficient Cities. *Transportation Research* A 22A (3), pp. 163-174

Newman. P.W.G, Kenworthy, J.R. 1989: Cities and Automobile Dependence. Aldershot, England: Gower Technical, pp. 34-67

Odum EP (1969) The strategy of ecosystem development. *Science.* CIV, 262-273

Odum, E.P. (1987) Fundamentals of Ecology, Saunders College Publishers, Philadelphia

Parkin, TB., Kaspar, TC., Senwo, Z. (2005) Relationship of soil respiration to crop and landscape in the walnut creek watershed, Journal of Hydrometeorology 6(6), 812-824

Pataki, D.E., Xu, T., Luo, Y.Q., Ehleringer, J.R. (2007) Inferring biogenic and anthropogenic carbon dioxide sources across and urban to rural gradient, Oecologia 152: 307-322

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Nilon, C.H., Pouyat, R.V., Zipperer, W.C., Costanza, R. (2001) Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas, Annu. Rev. Ecol. Syst. 32: 127-157

Pouyat, R., Groffman, P., Yesilonis, I., Hernandez, L (2002) Soil carbon pools and fluxes in urban ecosystems, Environmental Pollution 116: 107-118

Rapport, D.J. (ed. 2003) Managing for healthy ecosystems. Boca Raton, London, New York, Washington DC

Rees, E.R. (1996) Revisiting Carrying Capacity: Area-Based Indicators of Sustainability, Population and Environment 17: 195-215

Roberts, D.W. (1987) A dynamical systems perspective on vegetation theory, Vegetatio 69:27-33

Schmidt, K., Grose Starmann, K., 2006: Kommunen im Wandel, Aus Politik und Zeitgeschichte, 21/22, 10-17

Schmidt, P.I., 2006: Querschnittsbetrachtung Mecklenburg-Vorpommerns als Beispiel fur den demographischen Wandel in landlichen regionen Ostdeutschlands, Akademie fur Raumforschung und Landesplanung, 226, 263-278

Smith, R.D. and E. Maltby (2008) Using the ecosystem approach to implement the convention on biological diversity. IUCN Publications, Cambridge

Sukhdev, P. (2008) The economics of ecosystems and biodiversity, an interim report, European Communities, 2008

Schneider, E.D., Kay, J.J. (1994) Life as a manifestation of the second law of thermodynamics. *Mathematical and computer modelling* 19 (6-8), 25-48

SENSOR Integrated Project (2006) Newsletter No 4. www.sensor-ip.eu

Ulanowicz, R.E. (2000) Ascendency: A measure of ecosystem performance. In: Jørgensen, S.E., Müller, F. (eds.) Handbook of ecosystem theories and management. Boca Raton, 303-316

Vitousek, P.M., Aber, J.D., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H., Tilman, D.G. (1997) Human Alteration of the Global Nitrogen Cycle: Sources and Consequences, Ecological Applications, 7(3): 737-750

Waltersbacher, M., 2004: Konsequenzen aktueller Entwicklungen bei den Haushalten für den Wohnungsneubau in den alten Landern, Informationen zur Raumentwicklung, 3, 187-198

Warren-Rhodes, K., Koenig, A. (2001) Escalating trends in the urban metabolism of Hong Kong: 1971-1997, Ambio 30(7): 429-438

Wessolek, G. (2008) Sealing of Soils, In: Marzluff, J.M., Shulenberger, E., Endlicher, W., Alberti, M., Bradley, G., Ryan, C., ZumBrunnen, C., Simon, U. (eds.) Urban Ecology, pp.161-180, Springer

Wessolek G, Trinks S, Duijnisveld WHM (2004) Entwicklung von Boden- und nutzungsspezifischen Regressionsgleichungen zur Ermittlung der Sickerwasserrate aus dem Boden: das TUB-BGR-Verfahren. Bundesanstalt für Geowissenschaften und Rohstoffe, Feozentrum Hannover, TU Berlin. Berlin. Hannover.

Westra, L., Lemons, J. (eds.,1995) Ecological integrity and the management of ecosystems. St. Lucie Press, Ottawa

Wiggering, H. and F. Müller (2004) Umweltziele und Indikatoren. Berlin, Heidelberg, New York, 648 pp.

Whittaker, R.H. (1967) Gradient analysis of vegetation, Biological Reviews 49: 207-264

Wong, C. (2006) Indicators for Urban and Regional Planning, The RTPI Library Series, Routledge Taylor & Francis Group, London, New York

Woodley, S., Kay, J.J., Francis, G. (1993) Ecological integrity and the management of ecosystems. Ottawa

York, R. (2007) Demographic trends and energy consumption in European Union Nations, 1960-2025, Social Science Research 36: 855-872

Zheng, X.-P. (1991) Metropolitan Spatial Structure and its Determinants: A Case-study of Tokyo, Urban Studies 28(1) 87-104