Ex ante impact assessment of land use changes in European regions – the SENSOR approach

Katharina Helming[1], Karen Tscherning[1], Bettina König[1], Stefan Sieber[1], Hubert Wiggering[1], Tom Kuhlman[2], Dirk. Wascher[3], Marta Perez-Soba[3], Peter Smeets[3], Paul Tabbush[4], Oliver Dilly[5], Reinhard Hüttl[5], Hanne Bach[6]

(1) Leibniz-Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany
(2) Agricultural Economics Research Institute (LEI), The Hague, The Netherlands
(3) Alterra Green World Research. Wageningen, The Netherlands
(4) Forestry Commission Research Agency. Alice Holt, United Kingdom
(5) Chair of Soil Protection and Recultivation, BTU Cottbus, Cottbus, Germany
(6) National Environmental Research Institute (NERI), University of Aarhus, Roskilde, Denmark

Abstract

Land use includes those human activities that exhibit a spatial dimension and that change the bio-geophysical conditions of land. Land use policy making at European level aims at fostering sustainability pathways of natural resource use and rural development through the decoupling of economic growth from environmental degradation while supporting social cohesion in rural areas. Targeted policy making requires tools for the *ex ante* assessment of impacts of policy driven land use changes on sustainable development opportunities in European regions. These tools have to cover all relevant land use sectors and impact issues including their interrelations. They have to be spatially explicit, allow scenario analysis of possible future developments, be based on reproducible analyses, and be transparent and easy to use. The European Commission funded Integrated Project

SENSOR is dedicated to develop such *ex-ante* Sustainability Impact Assessment Tools (SIAT) for land use in European regions. SIAT is designed as a meta modelling toolkit, in which global economic trend and policy scenarios are translated into land use changes at 1km² grid resolution for the area of Europe. Based on qualitative and quantitative indicator analyses, impacts of simulated land use changes on social, environmental and economic sustainability issues are assessed at regional (NUTS2/3) scale. Valuation of these impacts is based on the concept of multifunctionality of land use. It is conducted through expert and stakeholder valuations leading to the determination of sustainability choice spaces for European regions. This paper presents the analytical approach in SENSOR and describes the impact assessment framework.

Keywords

Land use, scenario studies, integrated impact assessment, indicator analysis, modelling, participation, land use functions, multifunctionality, sustainability valuation

1 Introduction

Land use changes and their related impacts are the central object of the analysis of this study. The term land use is understood to imply those human activities that exhibit a spatial dimension and that change the biogeophysical conditions of land and the environment. From the spatial viewpoint, land use is among those human activities that have strongest impact on the environment worldwide. Concerns about environmental impacts of land use changes are not new. Extensive literature exists on the relations between land use patterns and intensities and environmental impacts, e.g. soil degradation (Pimentel, 1993; Boardman and Poesen, 2006), desertification (Reynolds and Staffort Smith 2002; Geist, 2005), water quality and biotic diversity (Poschlod et al., 2005). Interrelations between land use changes and ecosystem robustness and resilience have also intensively been studied (e.g. Metzger et al., 2006). In recent years, the role of land use in accelerating/mitigating climate change processes has gained focus (IPCC, 2001, Graveland et al., 2002). Increased understanding of the relations between land use changes and environmental impacts have been triggered by a series of studies related to the Land-Use and Land-Cover Change project (LUCC) of the International Geosphere-Biosphere Programme (IGBP) and International Human Dimension programme on

Global Environmental Change (IHDP) (Lambin et al., 1999). When compared to environmental impacts, social and economic aspects of land use changes are less well understood. They are mostly analysed in the context of driving forces for land use changes.

In recent years, modelling and foresight studies of land use change have emerged that place land use into the logical chain of driving forces and impacts (Veldkamp and Verburg, 2004; Verburg et al., 2006). For example, the ATEAM project (Advanced Ecosystem Analysis and Modelling) has undertaken scenario based simulations on global climate and land use change impacts on ecosystem vulnerability in Europe (Rounsevell et al., 2006). Building upon this study, the EURURALIS project also addressed a choice of socio-economic impacts associated with land use changes predominantly in the agricultural sector (Klijn et al., 2005). The method allowed the anticipation of possible impacts of economic trend and policy choices on agricultural developments and related sustainability issues. Also for the agricultural sector the SEAMLESS project developed an approach for multi-scale modelling to assess sustainability impacts of agricultural policies (van Ittersum et al., 2008). PRELUDE was another study on scenarios for future land use changes in Europe conducted by the European Environmental Agency (Hoogeven and Ribeiro, 2007). Designed as a facilitation instrument for public debate on landscape visions, various stakeholders elaborated a set of antithetic scenario narratives to envision landscape appearance in 30 years time. Extreme and partly shock based socio-economic developments and land use decisions were important features of these scenarios.

The here reported approach of SENSOR can be seen along the lines of the above mentioned studies but aims at developing *ex-ante* assessment tools for policy support that fully integrate social, economic and environmental impacts of policy driven land use changes at European scale. SENSOR "*Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects on Multifunctional Land Use in European Regions*" is funded by the European Commission FP6 framework research programme to develop tools for ex-ante impact assessment for European policies related to rural land use (Helming et al., 2006). To be policy relevant, the approach had to consider simultaneously the spatially relevant aspects of those economic sectors and activities that are involved in rural land use at European level. These include agriculture and forestry as main sectors, transport and energy infrastructure, rural tourism, and nature conservation as a 'regulatory activity' occupying land. In analysing driving force and policy scenarios for medium term perspectives (10-20 years), economy driven land use changes between these sectors and activities, their interrelations and their impacts on environmental, social and economic parameters affecting multifunctionality and sustainable development were to be assessed (Figure 1). This chapter describes the analytical approach of the SENSOR project in developing *ex-ante* impact assessment tools for European land use policies. Its objectives are (i) to provide the context of sustainable development, land use multifunctionality and impact assessment, in which the project is placed, and (ii) to weave the logical thread through the project's analytical design.

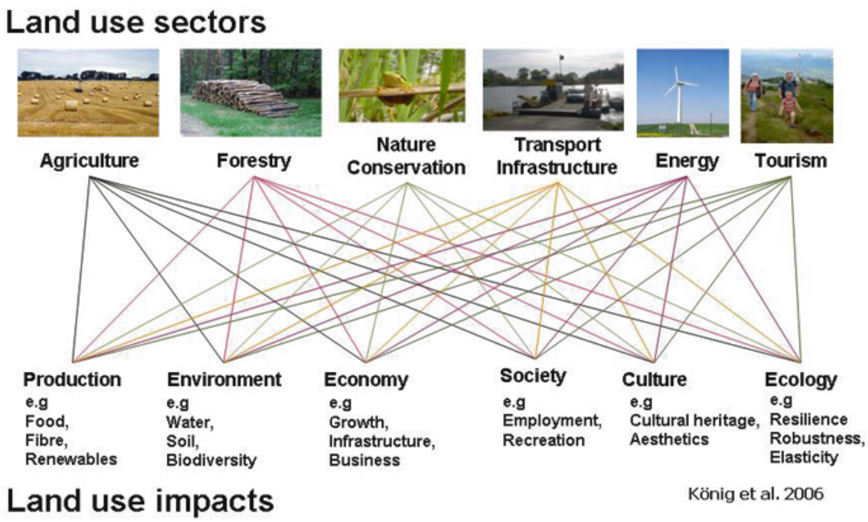

Fig. 1. Land use sectors and impacts analysed in SENSOR.

2 Sustainable development and multifunctional land use

Since the UN Conference on Environment and Development in 1992, sustainable development has been raised to a comprehensive conceptual approach. It has become a pioneering programme for politics to cope with the common future of humankind. This also implies relevancy to the future shaping of rural areas and the development of future land use systems. The significance of the sustainability concept in international debates can be attributed to its use in the Brundtland Commission's report *Our Common Future* (WCED 1987). This report emphasised the economic aspects of sustainability by defining sustainable development as "economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." For the case of agriculture, the term was further defined in the mission statement of the Consultative Group on International Agricultural Research (CGIAR) as "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" (CGIAR 1995). The terminology implies a strong normative, value driven component, which makes it attractive for policy makers, but at the same time severely challenges scientific analysis (Becker, 1997). On the one hand, scientific analyses of sustainability focus on the description of states and trends of a system through the determination of environmental, social and economic indicators and parameters. On the other hand, normative visions on ethical considerations, intergenerational equity and development targets have to be considered for valuing these states and trends in the light of deliberately defined sustainability targets. In this regard, sustainable development is interpreted as a procedural concept, in which societal debates on sustainable development targets are substantial features. This is also manifested in the European Commission's Sustainable Development Strategy (CEC, 2006).

For the case of land use and landscapes, the diversity of natural conditions and cultural systems prohibit the development of universally valid sustainability principles of land use and development. Therefore, regionally specific objectives of land use and land development must be defined that respond to the environmental and socio-economic characteristics of the respective region. The concept of multifunctionality is an attempt to specify the idea of sustainable development for the specific case of land use and landscape development (Wiggering et al., 2003). The underlying rationale for multifunctional land use is to consider social, economic, and environmental effects of any land use action interactively. In other words, commodity production is analysed in the context of its negative and/or positive externalities on environmental and social conditions of a spatial system. These effects are linked to spatially explicit geophysical and socio-cultural conditions of landscapes to provide "functions" or "services" in the landscape context (Costanza et al., 1997; De Groot et al. 2002). They include the provision of abiotic and biotic resources (water, soil, air, biotic integrity), the production of food, fibre and other biomass related products, the regulation, transformation, buffering and storage of energy and matter fluxes, the support of health, education and spiritual values including cultural heritage and recreation, and last but not least the basis for economic growth and social welfare. The multifunctionality of any land use action then lies in the degree to which land use affects the ability of the landscape to perform these various functions interactively (Barkman et al., 2004; Helming et al., 2007). This interpretation of multifunctionality can be confronted with a demand side in estimating societal demands for landscape functions. This would allow assessing the value of multifunctional land use to society. If sustainability is understood as a normative, discourse based process (WCED, 1987), then this multifunctionality concept can be used as an estimate for sustainability assessment of land use. Attempts have been undertaken to employ this concept (Helming and Wiggering, 2003; Cairol et al., 2005; Mander et al., 2007). The SENSOR approach for impact assessment is also based on this concept.

3 Impact Assessment tools for European policy making

Ex-ante impact assessment for European policy making is devoted to two major purposes: (i) better regulation and (ii) sustainable development (CEC 2005). The first item addresses the effectiveness and efficiency of the intended policy intervention with regard to the policy target (e.g. food production, rural development, conservation of natural resources). A number of tools and methodologies are available to analyse these questions, predominantly those based on Standard Cost Model (OECD, 2004) and Cost Benefit Analysis (CBA) (Hertin et al., 2007). The second purpose of sustainable development is more difficult to capture. It deals with externalities and addresses the occurrence of unintended side effects regarding social, economic and environmental variables of the system (Jacob et al., 2006). These effects might influence sustainable development of specific regions, societal groups or sectors. With this second aspect of IA a link between the objective of better regulation and the European Commission commitment to sustainable development (CEC, 2006) is made (Tabbush et al., 2008; Tscherning et al., 2008).

A number of studies have recently been undertaken to evaluate current impact assessment procedures at national and European level. Most impact assessments focus on the issue of better regulation and policy efficiency, while less effort is spent to the balanced analysis of impacts at all three sustainability dimensions (Jacob et al., 2007). This focus might be explained with preferences of decision making bodies. However, the integrated analysis of sustainability impacts is also hindered by a lack of tools and methods that provide the causal knowledge and linkage between policy intervention and sustainability impacts (Bartolomeo et al., 2004). Sustainability A-test (Van Herwijnen, 2006) and IQ-tools (Böhringer and Löschel, 2006) were two recent European projects that conducted comprehensive inventories of impact assessment tools for a variety of policy fields. It became obvious that most of these tools cover only isolated aspects of impact assessment such as scenario analysis or accounting approaches.

SENSOR, in producing a Sustainability Impact Assessment Toolkit (SIAT), focuses on the ex-ante assessment of unintended policy effects on the three sustainability dimensions for the case of land use. The toolkit was designed to support policy making on land use at European level. The tool aims to be robust and easy to use while being based on scientifically sound and reproducible procedures. A number of methodological challenges were associated with the analytical design. The analyses had to be prospective, build across disciplines, sectors and sustainability dimensions, be spatially explicit and include the valuation of simulated environmental, social and economic effects in terms of sustainability impacts. In essence, three consecutive questions had to be answered (see figure 2): (a) what kind of land use changes would happen as a consequence of policy intervention, (b) where will they happen, and (c) do these changes possibly induce an impact on sustainability pathways of respective regions?

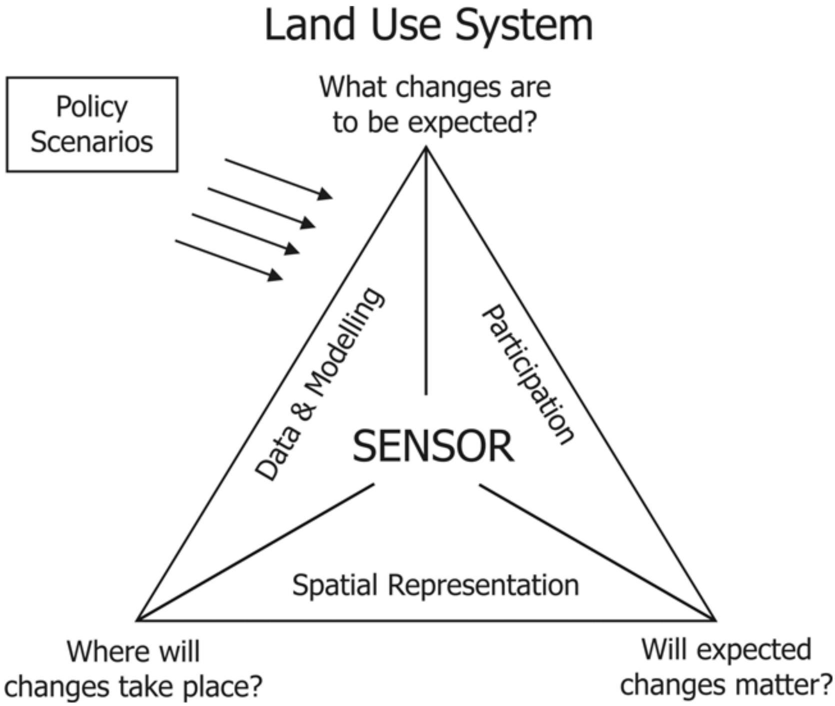

Fig. 2. General questions to be answered with the Impact Assessment in SENSOR

The major challenge for SIAT was to derive a trade-off between full flexibility of policy analysis on the one side, and robust, quick and easy-to-use performance on the other. A comprehensive study of end user requirements and institutional settings at this level preceded the design of SIAT (Thiel and König, 2008). In brief, the analysis revealed that the entire tool should be 'user friendly' with simple, clearly arranged operator panels for end users, whereas the framework of the model had to be 'flexible' (expandable to new policy scenarios). SIAT should be a stand-alone software product without specific hardware or user restrictions. The methodology should be transparent, each methodological step traceable, concise in its illustrations and transparent regarding assessment and data quality. Analysis with SIAT should focus on a broad understanding of cross-cutting trade-offs of land use impacts by a given policy and less on precise accuracy of very specific, detailed policy instruments. To achieve the fast and robust performance, SIAT was realised as a meta-modelling tool, in which models were not directly linked, but in which results of multiple scenario simulations derived from a series of models span a solution space within which future policy options can be analysed (Sieber et al., 2008, Jansson et al., 2008).

4 Analytical design and causal chain concept for impact assessment in SENSOR

The basic idea behind the analytical chain in SENSOR is to (i) link policy options with land use changes, (ii) link land use changes with environmental, social and economic impacts and (iii) provide a valuation framework of these impacts in the light of sustainable development. Seemingly simple, this approach requires complex interdisciplinary cooperation. Most European policies related to land use are economic instruments in the widest sense. Therefore, the link between policy options and land use changes is predominantly an economic issue, but is placed into specific bio-geophysical and socio-cultural settings, different sectors and governance levels. Expertise in these various fields has to be integrated so as to understand land use interrelations with policies. The logical linkage between land use changes and environmental, social and economic impacts is also interdisciplinary. While the understanding of relations between land use changes and environmental impacts is already well advanced (e.g. Ojima et al., 1994), only few studies exist on the direct relation between land use changes and economic and social impacts (Slee, 2007).

In the SENSOR project numerous experts collaborate to analyse the logical cascade of policies – land use changes – sustainability impacts in its full extent. To agree on a logical thread, the DPSIR framework (Smeets and Weterings, 1999) was employed. Developed by the European Environment Agency (EEA) this is a powerful concept to mediate between different disciplinary viewpoints and agree on a common understanding of causal chain relationships between society and environment. It is an advancement of an earlier version developed by the OECD (OECD 2001) and is defined as "The causal framework for describing the interactions between society and the environment adopted by the European Environment Agency: *Driving forces, Pressures, States, Impacts, Responses*" (EEA). The approach has since been adopted in many studies where interaction between human behaviour and environment was at stake (Niemeijer and De Groot, 2006). It is particularly useful when scientific process knowledge has to be translated into knowledge for policy support such as e.g. in the Thematic Strategy for Soil Protection of the European Commission (Van-Camp et al., 2004). The specific strength of the DPSIR concept lies in its adaptability to many different objectives and scales of analysis.

In the SENSOR context, the basic definition of *Drivers*, *Pressures* and *Impacts* is straightforward. Land use change is defined as the *Pressure*. It is affected by two sets of external *Drivers*: (i) those spanning a future socio-economic and technological reference situation and (ii) policy *Drivers* (see section 4.1*)*. The role of *States* is taken by numerous social, economic and environmental parameters that are affected by land use changes and that are meant to provide an estimate of sustainability *Impacts*. This way, the analysis chain departs from a predominantly economic setting (*Drivers*) which is translated into a geophysical setting (land use *Pressures*) and further into an integrated system of the social, economic and environmental settings (sustainability *Impact*s). While the first part of translating drivers into pressures is undertaken with a purely positivist approach of quantitative modelling, the second part of translating pressures into impacts needs to also include normative components in order to embrace the value based character of the sustainability definition (WCED, 1987). This was obtained by expanding the impact component of the DPSIR framework into four consecutive impact steps (Fig. 3). The first step (Impact 1) employs a positivist approach in determining environmental, social and economic state and impact indicators. The second and third steps address the valuation of the indicator changes resulting from step 1. The methods include monetary and non-monetary valuation of indicator changes at regional, in some cases national scale (Impact 2) and assessment of the changes in relation to regional or national standard and threshold values (Impact 3). These two steps are not necessarily consecutive but rather complementary. In the last step (Impact 4) a multifunctionality approach is undertaken to aggregate indicators and their valuations into an integrated assessment of the room for manoeuvre within sustainability choices (Potschin and Haines-Young, 2008). Impact steps two to four are based on normative, partly participatory approaches. This analytical design aims to integrate the top-down data and indicator based modelling with a bottom-up, value driven participatory approach (Fig. 3). The approach to the driving force – pressure relation is further outlined in section 4.1, while the pressure – impact relations are further described in section 4.2.

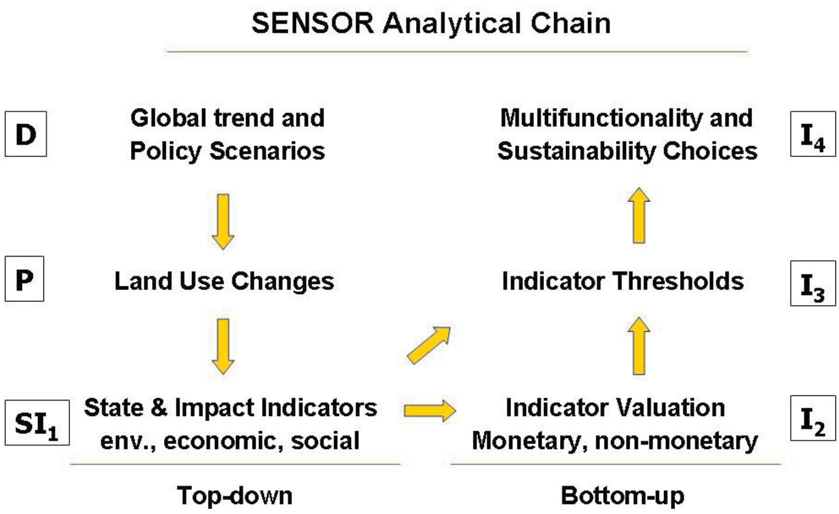

Fig. 3. Simplified analytical scheme of impact assessment in SENSOR integrating top-down modelling with bottom-up participatory approaches and extending on the DPSIR scheme of the EEA. *(D=Drivers, P=Pressures, S=State, I=Impact)*

The component of *Responses* within the DPSIR scheme is not taken up in the analytical design of SENSOR. In its logical setting, the *Response* component would be covered by policy decisions in reaction to simulated impacts. By theory, the policy decision would thus complete the DPSIR cycle. The SIAT tool, which is a translation of the analytical architecture of SENSOR into a decision support system, will help policy makers to comprehend the possible impacts of various scenario based choice options. The decision on the best policy choice itself is therefore exogenous to this tool and not taken up in the analysis scheme (Fig. 3).

4.1 Driving force scenarios for land use changes

The SIAT tool is constructed as a forecasting simulation tool in which future policy options can be analysed as to their possible sustainability impacts in a projection year of 2025. A reference scenario was necessary for such forecasts, presenting land use conditions that would be expected to develop in the absence of any change in policy intervention. To deal with uncertainties in forecasting exercises such as in SENSOR, a number of alternative scenarios are usually outlined that together present a continuous spectrum of possible future situations. Scenario approaches have been widely employed when it came to the need for designing coherent, internally consistent and plausible descriptions of possible futures that were driven by a complexity of interrelated factors (Morita et al., 2001; Alcamo et al., 2005). The development of scenarios was an integral part of prominent studies on environmental change, such as the *OECD Environmental Outlook* (OECD, 2001), the *Millenium Ecosystem Assessment* (MEA, 2003), or the *United Nations Environment Programme GEO-3* (UNEP, 2002) and the *European environment outlook* (EEA, 2005). Most attention was given to the climate change scenarios of the *Intergovernmental Panel on Climate Change* for climate change drivers and impacts (IPCC, 2000).

The general method of designing scenarios depends on the purpose of the study, the complexity of the issue and the available knowledge. It extends from purely probabilistic approaches to target oriented narratives. Probability theories are employed e.g. through stochastic Monte Carlo simulations of probability density functions in cases, where parameter determinants are to be treated in a purely stochastic manner such as in hydrology (see e.g. Samaniego-Eguiguren and Bárdossy, 2006). In contrast, most studies dealing with global economic and policy trends are of deterministic nature. In these cases, scenario storylines are elaborated, in which a set of internally consistent futures is constructed through the generation of logical parameter values for important driving forces (Rounsevell et al., 2006). A third approach to scenario development involves stakeholder visions to design normative scenario narratives. They are employed in cases, where visionary projections and planning strategies are needed (e.g. Volkery and Ribeiro, 2007).

Temporal projections, spatial scale (grain) and extent of analysis are further characteristics of scenario design. In SENSOR, scenario storylines were required as an input for macroeconomic and sector models to simulate future economic reference conditions for land use, on which policy options would impact. The projection year of 2025 was selected to meet decision maker's requirements for medium term perspectives. Driving forces were then identified that affect the economic situations in Europe for this time horizon and that could be simulated with the models under consideration. These were (1) demographic changes in Europe, (2) participation rate in the labour force in Europe, (3), growth of world demand, (4) oil prices at the world market, and (5) expenditure on research and development to simulate technological advance. Climate change related parameters were not considered in this study since current predictions state that climate change will not be of significant direct influence to land use within the time span of ten to twenty years considered in this study (IPCC, 2001). Based on the five drivers chosen, three scenario storylines were then constructed for the year 2025: business as usual, high growth and low growth scenarios (Kuhlman, 2008). These three scenarios were understood as bench marks within a continuum of possible economic futures (Fig. 4).

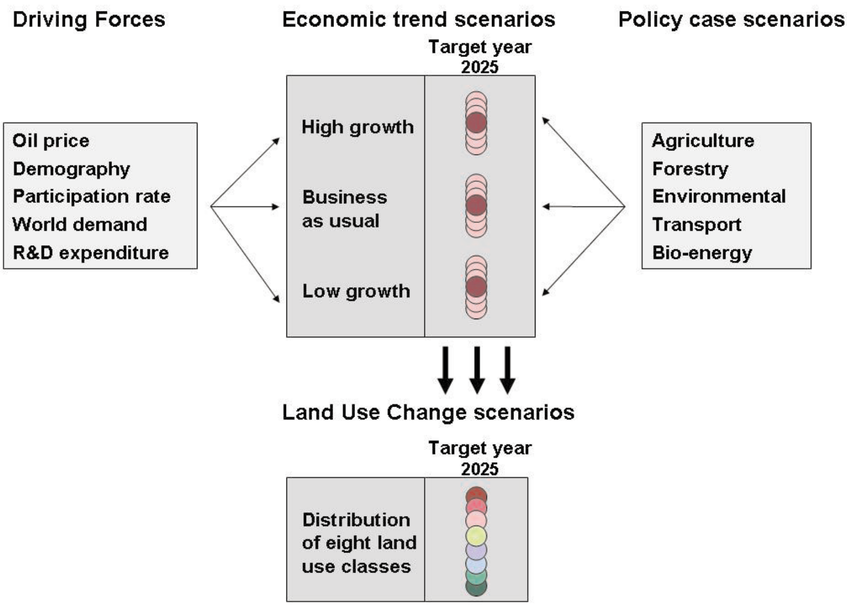

Fig. 4. Scenario design in SENSOR: three reference scenarios for economic trends in the target year of 2025 were constructed (dark purple dots). Policy case scenarios may superimpose on these scenarios (light purple dots). Economic trend scenarios were then translated into land use change scenarios (coloured dots).

Policy scenarios could be analysed against these future trends. The determination of policy scenarios is accommodated by the SIAT tool in the way that users can select among a choice of instruments for environmental, agriculture, forestry and bio-energy policy fields (Sieber et al., 2008). Scenario simulations were realised on the basis of response functions derived by coupling a macroeconomic model (NEMESIS – Fougeyrolla et al.,

2001) with sector models for agriculture (CAPRI – Heckelei and Britz, 2001) and forestry (EFISCEN – Karjalainen et al., 2003). Models for the other land use sectors (tourism, urbanisation, transport and energy infrastructure) were directly built into the macroeconomic model (Jansson et al., 2008). Resulting economic forecasts were then translated into land use simulations by linking sector models with the land use model CLUE-S (Verburg et al., 2002).

4.2 Indicator based assessment of land use changes

Scenario driven land use change simulations derived from CLUE-S model (Verburg et al., 2002) are the starting point for impact assessment in the analysis string of SENSOR. The model displays land use changes at 1 km² grid for eight land use classes: (1) rainfed arable, (2) irrigated arable, (3) biofuel arable, (4) grassland, (5) abandoned agricultural, (6) built-up, (7) forest, (8) semi-natural (Verburg et al., 2008). Special classes with little temporal dynamics (e.g. beaches, glaciers, bare rock, surface waters) are summarised in an extra category. With the subdivision of agricultural land use into five distinct categories (classes 1-5) credit was given to the fact that the highest land use dynamics as well as the most pronounced impacts are related to the agricultural sector (Verburg et al., 2008). Since focus was laid on rural land use in this study, urban land use and related activities (housing, waste disposal) were not explicitly considered.

In the first step of the impact assessment (I_1, Figure 3), an indicator based approach was employed to analyse environmental, social and economic state changes and impacts of scenario assumptions and land use changes. Indicators are widely used in decision support systems to condense and translate scientific knowledge into an information basis for decision support (EEA, 2006). It is therefore essential that the selection of indicators ensures relevancy and sensitivity to the purpose of the decision support system and to the demands of its users. For the SENSOR case, this requirement was met by linking the indicator selection to the list of impact issues that is contained in the official guidelines for Impact Assessment of the European Commission (CEC 2005). The list provides those topics that should be looked at in impact assessment and contains 10-12 impact issues for each of the three sustainability dimensions (see table 1). Each of these impact issues was analysed with respect to its sensitivity against policy induced land use changes. Those being sensitive were considered for the assessment.

Table 1. List of social, environmental and economic impact issues contained in the Guidelines for Impact Assessment of the European Commission (CEC, 2005)

SOCIAL Employment and labour markets; Standards and rights related to job quality; Social inclusion and protection of particular groups; Equality of treatment and opportunities, non-discrimination; Private and family life, personal data; Governance, participation, good administration, access to justice, media and ethics; Public health and safety; Crime, terrorism and security; Access to and effects on social protection, health and educational systems; Tourism pressure; Landscape identity; Migration
ENVIRONMENTAL Air quality; Water quality and resources; Soil quality and resources; The climate; Renewable or non-renewable resources; Biodiversity, flora, fauna and landscapes; Land use; Waste production / generation / recycling; The likelihood or scale of environmental risks; Mobility (transport modes) and the use of energy; The environmental consequences of firms' activities; Animal and plant health, food and feed safety.
ECONOMIC Competitiveness, trade and investment flows; Competition in the internal market; Operating costs and conduct of business; Administrative costs on business; Property rights; Innovation and research; Consumers and households; Specific regions or sectors; Third countries and international relations; Public authorities; The macroeconomic environment.

Based on a comprehensive analysis of existing indicator systems (Frederiksen and Kristensen, 2008) an indicator framework was then constructed that supported the selection of indicators for each of the selected impact issues. Indicator selection criteria were: (1) sensitivity to land use sectors relevant in SENSOR, (2) sensitivity to the reference and policy scenarios, (3) sensitivity in relation to the time frame (2025) and spatial system (Europe at regional, NUTS2/3 scale), (4) data availability and operability. As a result, about 40 indicators were selected such that each of the sensitive impact issues of the EC Impact Assessment Guidelines (CEC 2005) could be described with at least one indicator. To determine the indicator values, indicator functions were constructed for each indicator that reflected the causal relationship between land use change and indicator value. Generally, indicators were quantified at NUTS2/3 scale or with higher (1 km²) resolution and re-aggregated to NUTS2/3. Deviation occurred for some of the social and economic indicators, where data restrictions only allowed for indicator determination at national level. Qualitative methods for indicator determination were employed in cases, where knowledge and/or data restrictions made quantifications impossible (Farrington et al., 2008).

One difficulty of this approach lays in the fact that in some cases the indicator values were not only affected by land use changes, but also by the driving force and policy scenarios themselves or by related internal sector adaptations (Fig. 5). This was particularly true for some of the social and economic indicators. For example, in the case of "employment", the economic trend scenarios themselves have no doubt a direct impact on employment in rural regions. They also affect consolidations within the analysed sectors, e.g. intensification in agriculture, which also has an impact on employment. Only in a third instance, employment would also be affected by land use changes, e.g. through an increase in bio-energy production on the costs of set-aside land (Fig. 5). Since land use change is the major subject of this project, land use change impact relationships were given preference in the indicator analysis.

The second step of impact assessment (I_2, Fig. 3) was devoted to the valuation of the analysed indicator changes in monetary and non-monetary terms. The monetary valuation was based on an accounting framework for externalities to determine the monetary magnitude of external costs and benefits associated with observed indicator changes (Ortiz et al., 2007). The accounting framework was a simplified version of the Impact Pathway Approach (IPA) used in the European project *Externalities of Energy* (Extern E, 2005). The non-monetary valuation employed internet-based and group valuation methods to reveal stakeholder targets and preferences with respect to land use change impacts (Romano and Ferrini, 2007).

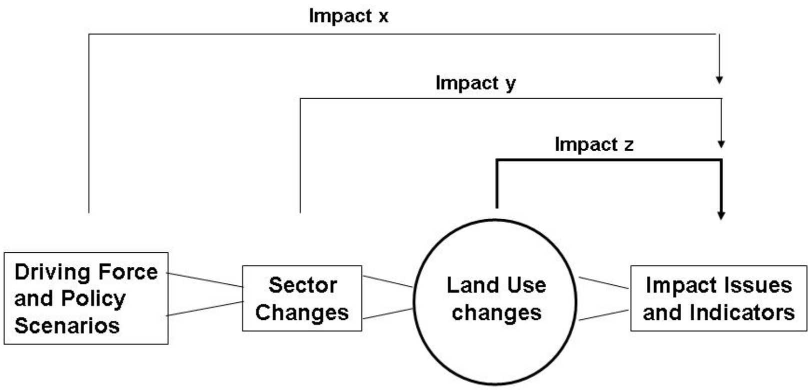

Fig.5. Causal relations between driving forces, sector changes, land use changes and impact issues. SENSOR focused on the relation between land use changes and impact issues (Impact z).

The objective was to cover the question of: "do the simulated changes matter" of Figure 2 in a regional context.

The third step of impact assessment (I_3, Fig. 3) was to confront the analysed changes in impact indicators (step 1) with respective regional and/or national threshold values. The approach was based as far as possible on available, published thresholds and/or standards for respective indicators (Bertrand et al., 2008).

4.3 Multifunctionality assessment and sustainability interpretation

Finally, the fourth step of impact assessment (I_4, Fig. 3) was to consolidate the assessment results into a sustainability interpretation. So far, impact analyses of step 1 to step 3 were concentrated on a series of impact issues of the environmental, social and economic sphere without considering their interweaved sustainability implications. This approach to a separate analysis of the three dimensions of sustainability is often summarised as *Triple Bottom Line* (TBL) (Elkington, 1998). TBL has become standard in many studies related to land use and agriculture impacts, e.g. in the Italian INEA study (Trisorio, 2004) or with the terminology of "People, Planet, Profit" in the EURURALIS study (Klijn et al., 2005).

Attempts to assess sustainability impacts with an integrating approach are only recently emerging (Wiek and Binder, 2005). For the case of land use and landscape development, the concept of multifunctionality has evolved as one key concept to operationalise sustainable development (Wiggering et al. 2006; Cairol et al., 2005). Initially, multifunctionality was a purely economic concept linked to the agricultural sector (Van Huylenbroeck et al., 2007). It was developed to recognise the environmental and social services and non-market outputs in addition to the primary purpose of agriculture in producing food and fibre (Maier and Shobayashi, 2001). By linking the supply based concept of joint multifunctional production to an estimation of social demand for such functions, the concept can be made operational for rural development and policy design (Durand and van Huylenbroek, 2003; Bills and Gross, 2005; Kallas et al., 2007). Links to sustainability assessment can also be made (Barkman et al., 2004; Piorr et al., 2006, Zander et al., 2007). In relation to SENSOR, the drawback of this concept is twofold: (i) it is purely restricted to agriculture, (ii) territorial characteristics and landscape specificities are not considered.

Parallel and independent to the concept of multifunctional agriculture, the concept of landscape and/or ecosystem functions emerged in the area of landscape and ecosystem ecology (e.g., Forman and Godron, 1986; Naveh and Lieberman, 1994). The idea behind this strongly territorially oriented concept is that natural and semi-natural ecosystems provide goods and services to human society that are of ecological, socio-cultural or economic value (Costanza et al., 1997). Here, the terms “functions” and ‘goods and services’ are often used synonymously. The ecosystem function approach has been conceptualised towards the valuation of ecosystem goods and services for the Millennium Ecosystem Assessment (MEA, 2003), in which World’s ecosystems were categorised and valued with respect to their provisioning, regulation, supporting and cultural functions affecting human well being. To date, the MA has been widely acknowledged as an extensive concept for linking environmental processes to human well being in the widest sense (Beck et al., 2006). For the case of cultivated landscapes such as analysed in SENSOR, in which economy driven land use plays a dominant role, the MEA concept is difficult to apply (Jones et al., 2006). This is because (i) it was predominantly developed for natural and semi-natural ecosystems and (ii) it addresses social and economic issues only indirectly as a consequence of environmental changes (de Groot, 2002). A bias towards the environmental dimension is therefore inherent in these approaches (Mander et al., 2007).

In SENSOR, an approach to ‘Land Use Functions’ (LUF) was undertaken that builds upon a combination of the above concepts of multifunctionality and of ecosystem services. It considers three perspectives of multifunctionality (Fig. 6):

- The land use perspective addressing the production side of land use functions.
- The landscape perspective that takes account of the territorial geophysical and socio-cultural capital to provide land use functions.
- The societal perspective that reveals demands and priorities towards land use functions.

The Land Use Functions are defined as those services or functionalities that are produced through land use in its interaction with the geophysical and socio-cultural capital of the landscape. In the SENSOR context, nine LUF were identified (Perez-Soba et al., 2008): ‘Provision of work’, ‘Human health and recreation’, ‘Cultural landscape identity’; ‘Residential and non-land based industries and services’, ‘Land based production and Infrastructure’, ‘Provision of abiotic resources’ (water, soil, air), ‘Support and provision of habitat’ (biodiversity, gene pool) and ‘Maintenance of ecosystem processes’.

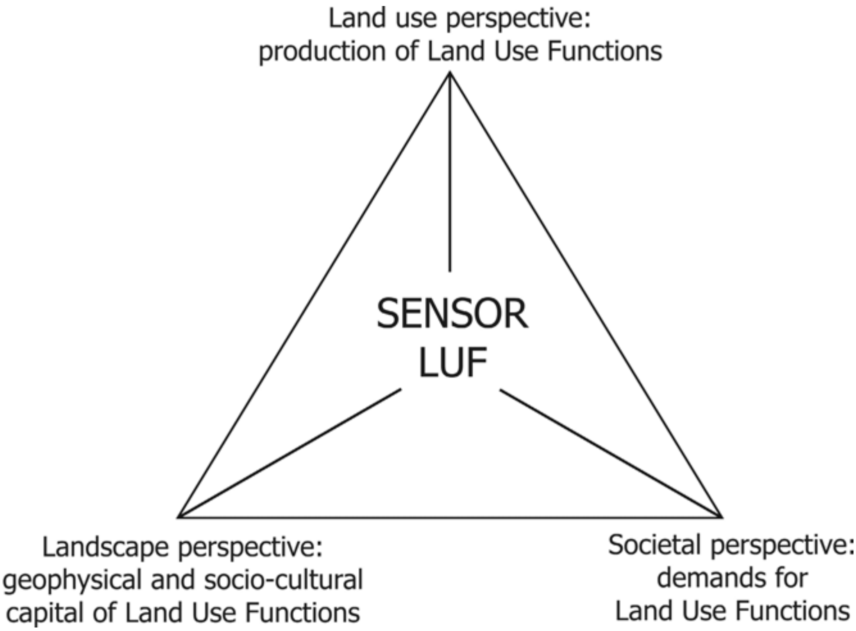

Fig. 6. Approach to Land Use Functions in SENSOR that considers the three perspectives of (1) land use related production, (2) landscape capital, and (3) societal demand to land use functions. *(LUF = Land Use Functions*)

The impact of land use simulations on the performance of these nine LUF was characterised for each region in Europe. This was done with the use of the impact indicators (step 1 above) and based on a Spatial Reference System for European regions (see section 5). It included two steps: (i) quantifying the contribution of each indicator to each LUF and (ii) developing knowledge rules to assess the importance of each LUF for the sustainability of each region. Step two allowed the introduction of a regional specificity into the interpretation of change of pan-European indicators. As a result, the assessments of land use change impacts in SENSOR funnelled into an estimate of changes of the performance of these nine Land Use Functions (Perez-Soba et al., 2008).

When it comes to sustainability assessment, the approach has two important implications: (1) it reduces the confusing complexity of 40 indicators into nine categories of Land Use Functions (see Fig. 7), and (2) it provides an operational basis for stakeholder driven valuation of anticipated changes. This brings us back to the normative notion of sustainability. Adopting sustainable development as a value based concept, in which human needs are the main objective function (WCED 1987), a societal discourse based valuation of sustainability implications is warranted. In displaying the land use policy induced changes of Land Use Functions, alternative policy outcomes can be compared in their implication to these functions simultaneously. Decision makers can then explore the 'room for manoeuvre' in setting targets and limits to these functions creating a 'Sustainability Choice Space' within which sustainable solutions can be achieved (Potschin and Haines-Young, 2008).

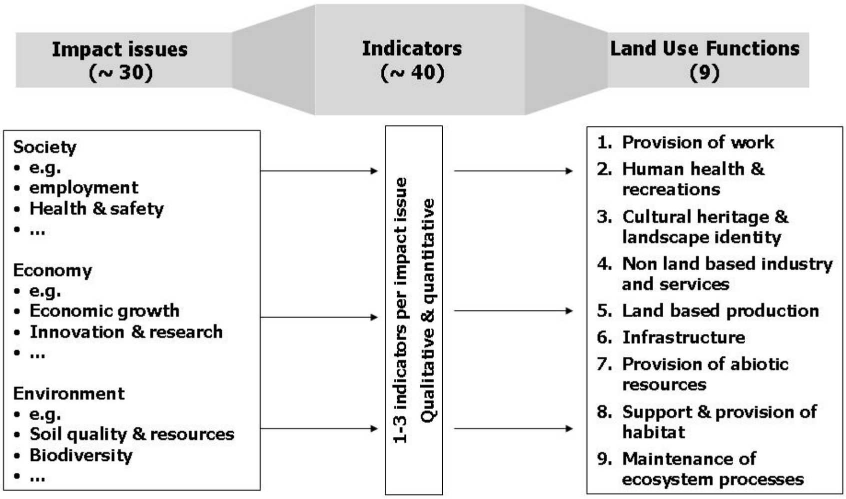

Fig. 7. Relation between impact issues as listed in the EC Impact Assessment Guidelines (Table 1, CEC 2005), indicators and Land Use Functions in SENSOR.

5 Spatial Approach and data management

The mission of SENSOR was to deliver impact assessment for policy making related to land use for the areas of the European Union at regional scale. This implied four important constraints for the spatial and data concept:

1. The area of Europe (EU27) had to be covered and European regions made comparable in their reaction to policy input.
2. Policy relevant, administrative units had to be used for the regional delineation of area boundaries.

3. Particularly the analysis of environmental impacts required higher than regional resolution and context based geophysical delineations of area boundaries.
4. The use of SIAT as a decision support tool required that the vast amount of assessment results were reduced in complexity through area based and thematic aggregation. The result had to be lower than regional resolution.

The first constraint was seemingly simple but had important implications for the analysis. Comparability of results required that all data used for the analysis were harmonised and available across the areas of Europe. To accommodate this, exclusively pan-European existing and quality proved data were used for the assessment. A GIS-based data management system for sustainability impact assessment of land use was developed, which (i) satisfied end-users needs, (ii) could be employed for regional assessments at EU27 scale beyond the lifetime of the project, and (iii) was compatible with major data gathering and data management initiatives such as GEO (http://earthobservations.org) (Hansen et al., 2008). For quality assurance the system is compliant with the INSPIRE principles on architecture, standards and metadata (INSPIRE, 2002).

The second constraint required regional delineation of area boundaries. For Europe, regional area units are hierarchically delineated in the NUTS systems, which is the *Nomenclature of Territorial Units for Statistics* of the European statistical office (Eurostat). Area sizes of the regions depend on the respective national administrative system and vary considerably between countries. Since harmonised areas sizes of regional boundaries were essential particularly for environmental analysis, a spatially homogenised combination of NUTS2 and NUTS3 regions was elaborated. This was done based on an earlier approach performed by the European Environmental Agency (EEA) in the frame of the IRENA project (EEA, 2006) and extended to the 12 new EU member states. The result was a NUTS-X map with 475 units for the area of Europe, which was used as the standard spatial system in SENSOR (Renetzeder et al., 2006).

The third constraint addressed the need for higher than regional spatial resolution for the analysis of environmental impacts of land use changes. This could be realised with the adoption of the land use model CLUE-S in the analysis chain, which operates at 1 km^2 resolution for the area of Europe (Verburg et al., 2002).

The fourth constraint reflected the need to support the thematic aggregation of assessment results into a manageable number of area delineations that reflect the interrelations of socio-cultural, economic and environmental settings on which this project was based. The challenge behind this was to acknowledge the high degree of cultural and natural diversity that exists between European regions (Wascher, 2003) and derive a regional characterisation that equally accounts for bio-geophysical and socio-economic characteristics. The result was a Spatial Regional Reference Framework (SRRF) clustering Europe into 27 regions based on geophysical and socio-economic parameters (Renetzeder et al., 2008).

In summary, the analytical work in SENSOR involved three spatial levels, namely (1) NUTS-X (combination of NUTS2 and NUTS3) as general level, (2) 1 km^2 grid based on the CLUE model for environmental analysis, and (3) a European cluster map with 27 regions integrating geophysical and socio-economic characteristics. For further description of the spatial system, see Renetzeder et al. (2008).

6 Validation and case study testing

To develop decision support tools for policy makers, the analytical chain described above was integrated into the Sustainability Impact Assessment Tool, the SIAT (Sieber et al., 2008). SIAT was realised in the form of a meta-modelling tool in which the modelling cascade and related interrelations of analytical steps was achieved through a series of pre-run global economic trend and policy scenarios. Together they span a solutions space within which SIAT users can define specific policy cases and run the analytical chain (Sieber et al., 2008). In doing so, the models were adapted to the specific requirements in SENSOR and validated separately (Jansson et al., 2008). However, not only did the models have to be tested for validity, but also the analytical concept. Questions had to be answered on whether (1) the most relevant issues regarding land use change and sustainability implications were addressed, (2) the logical linkages between economic trends, policy options, land use changes and sustainability impacts were comprehensible, and (3) the results were plausible. Respective to the analytical design of SENSOR, these three questions entailed a data related component and a value related normative component. To analyse the data related component of the three questions, a series of six case study areas was implemented across Europe. In each of these areas a comprehensive analysis of sustainability issues related to land use and sustainability problems was obtained (Dilly et al., 2008). Extensive data mining and analysis then provided a thorough basis upon which the analytical approaches for indicator determination could be tested. This way, information loss could be determined that arose from the exclusive use of pan-European available data for regional assessment. Regional policy analysis also revealed key sustainability issues as related to land use. This information could be used to check the relevancy of impact issues, indicators and Land Use Functions as analysed in SENSOR (Dilly et al., 2008)

The normative component of validation was based on a participative approach and aimed at identifying societal perspectives regarding land use and sustainability interrelations. In this respect, two groups of stakeholders had to be consulted. The first group was identified as "*problem solvers*" and resembled the possible end users of the final SIAT tool. This group is constituted of policy makers at European Commission level in the widest sense. It also includes research authorities at European level that might assist policy making in applying tools such as SIAT. Several consultancy meetings were arranged throughout the design phase of SIAT in order to include reactions and comments to the SIAT design. This process was also preceded by a comprehensive study on end user requirements and institutional settings related to impact assessment at European level (Thiel and König, 2008). This way, a targeted design of the analytical concept in SENSOR as well as of the operational features of SIAT was aimed to be achieved.

The second group of stakeholders was identified as "*problem owners*". This group represents stakeholders at regional level that are actually affected by sustainability implications of land use changes. Extensive stakeholder sessions were conducted in each of the case study areas to validate the logical thread of SENSOR and identify similarities and differences regarding sustainability issues of land use (Morris et al., 2008). The sessions were organised such that each analytical step in SENSOR was mirrored by stakeholder based estimates on the logic behind and plausibility of results. This way, similarities and differences between expert and data based analysis on the one hand, and stakeholder based analysis on the other hand, could be achieved. This approach complemented the plausibility checking of the SENSOR approach (Morris et al., 2008).

7 Conclusions

SENSOR is a four year project designed to develop *Sustainability Impact Assessment Tools* (SIAT) in relation to land use in European regions. The various disciplinary approaches, analysis scales as well as the complementarity between quantitative modelling and indicator-based analysis on one hand, and qualitative, stakeholder driven approaches on the other, make the project complex. This paper provides an overview of the analytical design of the project. At the time this paper was written, the activities in

SENSOR were ongoing. The conceptual design was elaborated, but some of the results had yet to be substantiated. Emerging results and the actual use of the constructed SIAT tool will prove the validity and robustness of the analytical design described in this chapter.

Acknowledgements

This publication has been funded under the EU 6th Framework Programme for Research, Technological Development and Demonstration, Priority 1.1.6.3. Global Change and Ecosystems (European Commission, DG Research, contract 003874 (GOCE)).

References

Alcamo J, van Vuuren D, Ringler C, Alder J, Bennett E, Lodge D, Masui T, Morita T, Rosegrant M, Sala O, Schulze K, Zurek M (2005). Chapter 6. Methodology for developing the MA scenarios. In: Carpenter S, Pingali P, Bennett E, Zurek M (eds.) Scenarios of the Millennium Ecosystem Assessment, Island Press, Oxford

Barkman J, Helming K, Müller K, Wiggering H (2004) Multifunctional landscapes: towards an analytical framework for sustainability assessment of agriculture and forestry in Europe. Final Scientific Report. EU FP5 Project EVK-CT-2002-80023

Bartolomeo M, Giugni P, Hertin J, Jacob K, Rennings K, Volkery A, Wilkinson D, Zanoni D (2004) Approaches to Impact Assessment in six OECD countries and at the European Commission. IQ-Tools Project report, WP1A

Beck S, Born W, Dziock S, Görg C, Hansjürgens B, Henle K, Jax K, Köck W, Neßhöfer C, Rauschmayer F, Ring I, Schmidt-Loske K, Unnerstall H, Wittmer H (2006) The Millenium Ecosystem Assessment and its relevance for Germany. UFZ-Report 2/2006, Leipzig (in German)

Becker B (1997) Sustainability assessment – a review of values, concepts and methodological approaches. Consultative Group on International Agricultural Research, CGIAR. Washington, United States

Bertrand N, Jones MLM, Hasler B, Omodei-Zorini L, Petit S, Contini C (2008) Limits and targets for a regional sustainability assessment: an interdisciplinary exploration of the threshold concept. In: Helming K, Tabbush P, Perez-Soba M (Eds). Sustainability impact assessment of land use changes. Springer, 405-424

Bills N, Gross D (2005) Sustaining multifunctional agricultural landscapes: comparing stakeholder perspectives in New York (US) and England (UK). Land Use Policy 22: 313-321

Boardman J and Poesen J (eds) (2006) Soil Erosion in Europe. Wiley, Chichester, UK

Böhringer C, Löschel A (2006) Computable General Equilibrium Models for Sustainability Impact Assessment, Ecological Economics 60 (1), 49-64

Cairol D, Coudel E, Barthélémy D, Caron P, Cudlinova E, Zander P, Renting H, Sumelius J, Knickel KH (2005) Multifunctionality of agriculture and rural areas: from trade negotiations to contributing to sustainable development. New challenges for research. Summary of main results from the MULTAGRI project

Commission of the European Communities (2005) Impact Assessment Guidelines. SEC (2005) 791

Council of the European Commission (2006) Review of the EU Sustainable Development Strategy – Renewed Strategy. 10917/06. Brussels, Belgium

Consultative Group on International Agricultural Research, CGIAR (1995) Report of the Task Force on Sustainable Agriculture. Document No. MTMi95110. Nairobi, Kenya. Washington, D.C.

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 the world's ecosystem services and natural capital. Nature 387, 253-260

De Groot RS, Wilson A, Boumans RMJ (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, 393-408

Dilly O, Rogaß C, Dörrie C, Schneider BU, Siebielec G, Stuczyński T, Korzeniowska-Pucułek R, Koza P, Kowalik M, Łopatka M, Pudełko R, Hallenbarter D, Kräuchi N, Imrichová Z, Putzhuber F, Hasenauer H, Oja T, Kull T, Mander Ü, Moncada S, Camilleri M, Formosa S, Gale R, Hüttl RF (2008) Key sustainability issues and the spatial classification of sensitive regions in Europe. In: Helming K, Tabbush P, Perez-Soba M (eds) Sustainability impact assessment of land use changes. Springer, 471-494

Durand G, van Huylenbroek G (2003): Multifunctionality and rural development: a regional framework, in: van Huylenbroek G, Durand G (eds.): Multifunctional Agriculture - A New Paradigm for European Agriculture and Rural Development, Ashgate, Aldershot, 1-16

European Environmantel Agency (EEA) (2005) European environment outlook. EEA report no. 4/2005. Copenhagen

EEA (2006) Integration of environment into EU agriculture policy – the IRENA indicator-based assessment report. EEA report no. 2/2006. Copenhagen

Elkington J (1998) Cannibals with Forks: the Triple Bottom Line of 21st Century Business. Gabriola Island

Extern E (2005) "Externalities of Energy: methodology 2005 update", Luxembourg: Office for Official Publications of the European Communities

Farrington JH, Kuhlman T, Rothman DS, Imrichova Z, Reid L, Konkoly E (2008) Reflections on social and economic indicators for land use change. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 325-347

Forman RTT, Godron M (1986) Landscape ecology. Wiley. New York

Fougeyrolla P, Le Mouël P, Zagamé P (2001) NEMESIS – New Factors Demands System: Dynamic Duality and Pooled Panel Estimation Techniques. – Working Paper NEMESIS No 3.2

Frederiksen P, Kristensen P (2008) An indicators framework for analysing sustainability impacts of land use change. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 293-304

Geist HJ (2005) The causes and progression of desertification. Ashgate Aldershot, Burlington

Graveland C, Bouwman AF, de Vries B, Eickhout V, Strengers BJ (2002) Projections of mutli-gas emissions and carbon sinks, and marginal abatement cost functions modelling for land use related sources. RIVM report 461502026. Bilthoven

Hansen HS, Viuf P, Loibl W, Peters-Anders J, Zudin S, Vogt J (2008) Requirement for data management and maintenance to support regional land use research. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 269-290

Heckelei T, Britz W (2001). Concept and explorative application of an EU-wide regional agricultural sector model (CAPRI-Projekt). In: Heckelei T, Witzke HP, Henrichsmeyer W (eds). Agricultural Sector Modelling and Policy Information Systems. Proceedings of the 65th EAAE Seminar, March 29-31, 2000 at Bonn University, Vauk Verlag Kiel, Germany, 281-290

Helming K, Wiggering H (eds) (2003) Sustainable Development of Multifunctional Landscapes. Springer Berlin, Heidelberg, New York

Helming K, König B, Tscherning K (2006) SENSOR first annual report (public part) In: Helming K, Wiggering H (eds): SENSOR Report Series 2006/1, http://zalf.de/home_ipsensor/products/sensor_report_series.htm, ZALF, Germany

Helming K, Sieber S, Tscherning, K, König, B, Müller K, Wiggering H, Kuhlmann T, Wascher D, Perez-Soba M, Tabbush, P, Dilly O, Bach H (2007) Land use functionality as a frame for impact assessment. In: Knierim A, Nagel UJ, Schäfer C (eds) Managing Economic, Social and Biological Transformations. Margraf Publishers. 33-44

Hertin J, Jordan A, Nilsson M, Nykvist B, Russel D, Turnpenny J (2007) The practice of policy assessment in Europe: An institutional and political analysis. Matisse, Working Paper 6. http://www.matisse-project.net/

Hoogeven Y, Ribeiro T (2007) Land Use Scenarios for Europe. Background Report. European Environmental Agency. Kopenhagen

IPCC (2000) Special report on emission scenarios (SRES). Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

IPCC (2001) Climate Change 2001. The Scientific Basis. Contributions of Working Group 1 to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge

INSPIRE (2002) INSPIRE Architecture and Standards Working Group Position Paper. http://inspire.jrc.it

Jacob K, Hertin J, Volkery A (2006) Considering environmental aspects in integrated Impact Assessment – lessons learned and challenges ahead. In: George C and Kirkpatrick C (eds): Impact Assessment for a New Europe and Beyond. Edward Elgar Publisher

Jacob K, Hertin J, Meuwese A, Radaelli R (2007). Preliminary Results from the Country Studies. EVIA (Evaluating Integrated Impact Assessment) report. Berlin, Germany

Jansson T, Bakker M, Boitier B, Fougeyrollas A, Helming J, van Meijl H, Verkerk PJ (2008) Cross sector land use modelling framework. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 159-180

Jones MLM, Petit S, Firbank L, Bertrand N, Geffard G, Rambolinaza M, Granjou C, Boudières V, Omodei-Zorini L, Contini C, Hasler B, De Groot D, Hein L, Luttik J (2006) Regional indicator threshold / risk assessment concepts and Land use Functional approach. SENSOR deliverable D3.2.1. In: Helming K, Wiggering H (eds.): SENSOR Report Series 2006/9, http://zalf.de/home_ipsensor/products/sensor_report_series.htm, ZALF, Germany

Kallas Z, Gomez-Limon JA, Arriaza M (2007) Are citizens willing to pay for agricultural multifunctionality? Agricultural Economics 26: 405-419

Karjalainen T, Pussinen A, Liski J, Nabuurs GJ, Eggers T, Lapveteläinen T, Kaipainen T (2003): Scenario analysis of the impacts of forest management and climate change on the European forest sector carbon budget. Forest Policy and Economics 5 (2): 141-155

Klijn JA, Vullings LAE, Lammeren RJA, van Meijl JCM, van Rheenen T, Veldkamp A, Verburg PH, Westhoek H, Eickhout B, Tabeau AA, (2005) The EURURALIS study: technical document. Alterra Report 1196. Alterra, Wageningen

Kuhlman T (2008) Scenarios – driving forces and policies. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 131-157

Lambin EF, Baulies X, Bockstael N, Fischer G, Krug T, Leemans R, Moran EF, Rindfuss EE, Sato Y, Skole D, Turner BL, Vogel C (1999). Land-Use and Land-Cover Change (LUCC) Implementation Strategy. IGBP and IHDP

Mander Ü, Wiggering H, Helming K (eds) (2007) Multifunctional land use – meeting future demands for landscape goods and services. Springer. Berlin Heidelberg

Maier L, Shobayashi M (2001) Multifunctionality: Towards an analytical framework (Agriculture and Food). Paris: OECD

Metzger MJ, Rounsevell MDA, Acosta-Michlik L, Leemans R, Schröter D (2006) The vulnerability of ecosystem services to land use change. Agric. Ecosyst. Environ. 114, 69-85

Millenium Ecosystem Assessment – MEA (2003). Ecosystems and Human Well-being: A framework for assessment. Island Press, Washington DC

Morita T, Robinson J, Alcamo J, Nakicnovic N, Zhou D (2001) Socio-economic and emissions scenarios. Chapter 2 in: Climate Change 2001: Mitigation,

Third Assessment Report, Working Group III of the Intergovernmental panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK
Morris J, Camilleri M, Moncada S (2008) Key sustainability issues in European sensitive regions – a participatory approach. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 451-470
Naveh Z, Lieberman AS, (1994) Landscape ecology : theory and application. 2nd ed., Springer-Verlag, New York.
Niemeier D, De Groot R (2006) Framing environmental indicators: moving from causal chains to causal networks. Environ Dev Sustain (online) DOI 10.1007/s10668-006-9040-9
OECD (2001). OECD Environmental outlook. OECD Paris
OECD (2004). The Standard Cost Model. A framework for defining and quantifying administrative burdens for businesses. OECD Paris
Ojima DS, Galvin KA, Turner BL (1994). The global impact of land use change. BioScience 44(5): 300-4
Ortiz R, Walton H, Taylor T, Arnold S, Markandya A (2007). Accounting Framework for the Assessment of Externalities. SENSOR Deliverable D2.3.4 In: Helming K, Wiggering H (eds). SENSOR Report Series 2007/6 http://zalf.de/home_ipsensor/products/sensor_report_series.htm, ZALF, Germany
Perez-Soba M, Petit S, Jones L, Bertrand N, Briquel V, Omodei-Zorini L, Contini C, Helming K, Farrington J, Tinacci Mossello M, Wascher D, Kienast F, de Groot R (2008) Land use functions – a multifunctionality approach to assess the impacts of land use change on land use sustainability In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 375-404
Pimentel D (1993) World soil erosion and conservation. Cambridge University Press, Cambridge
Piorr A, Uthes S, Waarts Y, Sattler C, Happe K, Mueller K (2006) Making the multifunctionality concepts operational for impact assessment. In Meyer BC (ed) Sustainable land Use in Intensively Used Agricultural Regions. Landscape Europe. Alterra Report No. 1338, Wageningen. 47-54
Poschlod P, Bakker JP, Kahmen S (2005) Changing land use and its impact on biodiversity. Basic and Applied Ecology 6(2) 93-98
Potschin M, Haines-Young R (2008) Making Sustainability Impact Assessments: Limits, Thresholds and the Sustainability Choice Space. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 425-450
Renetzeder Ch, van Eupen M, Mücher S, Wrbka T, Wascher D, Kienast F (2006) Spatial Regional Reference Framework (SRRF) – methodology and report. In: Helming K, Wiggering H (eds). SENSOR Report Series 2006/6a. http://zalf.de/home_ipsensor/products/sensor_report_series.htm, ZALF, Germany
Renetzeder C, van Eupen M, Mücher CA, Wrbka T (2008) Clustering Europe:A Spatial Regional Reference Framework for Sustainability Assessment. In:

Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 249-268

Reynolds JF, Staffort Smith DM (eds) (2002) Global Desertification: do humans cause deserts? Dahlem Report 88. Univ. Press. Berlin

Romano D, Ferrini S (2007) Review paper and data-base on monetary valuation sturides in Test Regions with special attention to the bio-energy policy case. SENSOR deliverable D3.3.2 In: Helming K, Wiggering H (eds). SENSOR Report Series 2007/8. http://zalf.de/home_ipsensor/products/sensor_report_series.htm, ZALF, Germany

Rounsevell MDA, Reginster I, Araujo MB, Carter TR, Dendoncker N, Ewert F, House JI, Kankaanpää S, Leemans R, Metzger MJM, Schmit C, Smith P, Tuck G (2006) A coherent set of future land use change scenarios for Europe. Agric. Ecosyst. Environ. 114: 57-68

Samaniego-Eguiguren LE, Bárdossy A (2006) Simulation of the Impacts of Land Use/Cover and Climatic Changes on the Runoff Characteritics at the Mesoscale. Ecological Modelling 196: 45-61

Sieber S , Müller K, Verweij P, Haraldsson H, Fricke K, Pacini C, Tscherning K , Helming K, Jansson T (2008) Transfer into decision support: The Sustainability Impact Assessment Tool (SIAT). In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 107-128

Slee B (2007) Social indicators for multifunctional rural land use: the case of forestry in the UK. Agriculture, Ecosystems and Environment 120(1): 31-40

Smeets E, Weterings R (1999) Environmental indicators: typology and overview. Report nr. 25. European Environmental Agency (EEA). Copenhagen, Denmark

Tabbush P, Frederiksen P (2008). Impact Assessment in the European Commisssion in relation to multifunctional land use. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 35-54

Thiel A, König K (2008) An institutional analysis of land use modelling in the European Commission. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 55-75

Trisorio A (2004) Measuring sustainability – indicators for Italian agriculture. INEA. National Institute of Agricultural Economics. Rome.

Tscherning K, König H, Schößer B, Helming K, Sieber S (2008) Ex-ante Impact Assessment (IA) in the European Commission – an overviw. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 17-33

United Nations Environment Programme – UNEP (2002) Gobal Environmental Outlook 3, Earthscan, London

Van-Camp L, Bujarrabal B, Gentile AR, Jone RJA, Monatanerella L, Olazabal C, Sevaradjou SK (2004) Report of the Technical Working Groups established under the Thematic Strategy for Soil Protection. EUR 21319 EN/1, 872 pp. Office for Official Publication of the European Communities, Luxembourg.

Van Herwijnen M (2006) Sustainability A-Test web-book http://ivm5.ivm.vu.nl/sat/

Van Huylenbroeck G, Vandermeulen V, Mettepenningen E, Verspecht A (2007) Multifunctionality of Agriculture: a review of definitions, evidence and instruments. Living Rev. Landscape Res. 1, 3 http://www.livingreviews.org/lrlr-2007-3

Van Ittersum MK, Ewert F, Heckelei, T, Wery, J., Alkan Olsson J, Andersen E, Bezlepkina I, Brouwer F, Donatelli M, Flichman G, Olsson L, Rizzoli AE, van der Wal T, Wien, JE, Wolf, J (2008). Integrated assessment of agricultural systems – a compnent-based framework for the European Union (SEAMLESS). Agricultural Systems 96: 150-165.

Veldkamp A, Verburg PH (2004) Modelling land use change and environmental impact. J. Environ. Manage. 72: 1-3

Verburg PH, Soepboer W, Veldkamp A, Limpiada R, Espaldon V, Sharifah Mastura SA (2002) Modeling the Spatial Dynamics of Regional Land Use: the CLUE-S Model. Environmental Management, 30 (3), 391-405

Verburg PH, Rounsevell MDA, Veldkamp A (2006) Scenario-based studies of future land use in Europe. Agric. Ecosyst. Environ. 114: 1-6

Verburg PH, Bakker M, Overmars K, Staritsky I (2008) Landscape level simulation of land use change. In: Helming K, Tabbush P, Perez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 211-227

Volkery A, Ribeiro T (2007) Prospective environmental analysis of land use development in Europe: from participatory scenarios to long-term strategies. Paper presented at the 2007 Amsterdam Conference on the Human Dimensions of Global Environmental Change "Earth system governance: theories and strategies for sustainability"

Wascher DM (2003). Overview on agricultural landscape indicators across OECD countries. In: Dramstad W and Sogge C (eds) Agricultural impacts on landscapes: developing indicators for policy analysis. Proceedings from NIJOS/OECD Expert Meeting on Agricultural Landscape Indicators in Oslo, Norway, October 7-9, 2002. 19-36

Wiggering H, Mueller K, Werner A, Helming K (2003) The concept of multifunctionality in sustainable land development. In: Helming K, Wiggering H (eds) Sustainable Development of Multifunctional Landscapes. Springer. 1-18

Wiggering H, Dalchow C, Glemnitz M, Helming K, Müller K, Schultz A, Stachow U, Zander P (2006) Indicators for multifunctional land use – Linking socio-economic requirements with landscape potentials. Ecological Indicators 6: 238-249

Wiek A, Binder C (2005). Solution spaces for decision making – a sustainability assessment tool for city-regions. Environmental Impact Assessment Review 25: 589-608

World Commission on Environment and Development WCED (1987). Our Common Future. New York: Oxford University Press

Zander P, Knierim A, Groot JCJ, Rossing WAH (2007): Multifunctionality of agriculture: Tools and methods for impact assessment and valuation (Editorial). Agric. Ecosyst. Environ. 120: 1-4