Validating a Meta-Model: The Example of Sustainability Impact Assessment Tools (SIAT) for European Land Use Analysis

Stefan Sieber[1] , Peter Verweij[2], Katharina Helming[1], Klaus Müller[1], Katharina Fricke[1], Dirk Pohle[1], Cesare Pacini[3], Torbjorn Jansson[4], Hördur Haraldsson[5], Karen Tscherning[1]

[1]Leibniz-Centre for Agricultural Landscape Research (ZALF e.V.), Germany
[2]Alterra, Green World Research, Wageningen, Netherlands
[3]Dept. Agronomy and Land Management, University of Florence, Italy
[4]LEI Agricultural Economics Research Institute, Netherlands
[5]University of Lund, Sweden

Abstract

The integrated meta-modelling approach SIAT is the central product of the project SENSOR (6th EU Framework Program), which innovates ex-ante impact assessments (IA) of European policy instruments. Analytical focus of this article is how to cope with the problem of system complexity regarding consistency and reliability of scenario outcomes. Thus, the iterative process of validating the meta-model SIAT is described in respect of undertaken measures.

SIAT enables end users to assess regional effects of land-use relevant EU-policy strategies and evaluate the impacts against sustainability criteria. SIAT focuses analytically on cross-sectoral trade offs of the six sectors agriculture, forestry, energy, transport, nature conversation and tourism. Policy effects of multifunctional land use are measured by sustainability indicators. Risk assessments are conducted by defining sustainable tolerance limits that determine the allowable range of sustainable developments.

The model design of SIAT is composed of mathematical response protocols, which are derived by quantitative modelling techniques solving iteratively linked components of a model framework. Complementary knowledge rules assure indicator calculations beyond modelling capacities in the form of qualitatively described responses as decision trees. All integrated methods need consistency checks across different scales from grid to EU-level and among indicator aggregations.

This article concludes that the complex meta-model system SIAT needs a set of individually applied measures to be able to assure reliable policy scenario results. Potential inconsistencies can be minimised by calibrating and validating used single models as well as the interacting model framework, but complementary ex-post evaluation of model results at disaggregated level of sensitive regions with stakeholder involvements is additionally an inalienable procedure.

Keywords: SENSOR, Policy Decision Support System; Meta-Modelling; Sustainability Impact Assessment; Validation

1 Introduction

The European Union funded Integrated Project SENSOR develops ex-ante *Sustainability Impact Assessment Tools* (*SIAT*) to support decision making on policies related to multifunctional land use in European regions (Helming et al. 2006).

SIAT supports identifying possible economic, environmental and social effects of policy options and its consequences with respect to sustainable development before and during its implementation[1]. The Integrated Impact Assessment process (EC, 2005) is thought to streamline, substitute and integrate all existing single sector assessments, including sustainability impact issues. SENSOR integrates three key assessment streams: (1) European-wide, indicator-based driving force and impact analysis of land use policy scenarios; (2) region specific problem, risk and threshold assessment making use of spatial reference systems and participatory processes; and (3) case study based, exemplary sensitive area studies in mountains, islands, coastal zones, post-industrialised areas using detailed information on specific sustainability issues (Helming et al. 2006). Key concept is the multifunctionality, which is regarded as a basic approach for implementing sustainable development in the field of land use (Wiggering et al. 2003).

In this regard, a module structure within SENSOR ensures the development of a set of methodological components to be integrated into SIAT:

- *European land use scenarios and impact assessment:* The European scale analysis of future scenarios for general socio-economic trends and specific land use policies illustrates possible land use changes, of which the impact on sustainability issues is analysed with indicator based methods. Methods to analyse the performance of reference and policy scenarios on land use change and their outcome on sustainability issues for European regions have been developed and tested. The results are provided as protocols for integration of methods into the SIAT.

- *Regional sustainability problems, risks and thresholds:* Regional dimensions of sustainability are assessed through indicator-based impact assessments by developing and making use of a Spatial Regional Reference Framework (SRRF). The framework provides region-specific information on rurality, urban structure, socio-economic profiles and landscape character information for each of the EU's administrative units (475 so-called NUTS-X regions, a spatially homogenised combination of NUTS 2 and 3 regions) and for 30 relatively homogenous clusters of these regions.

- *Integrated data management:* Spatial data availability in Europe is fragmented; gaps and a general lack of harmonisation between data sets at different geographical scales still exist.

[1] Model analyses with SIAT respond directly to the questions manifested in the Commissions Communication on Impact Assessment (EC, 2002) which introduced an internal process of impact assessment for major policy proposals in all policy areas.

An overall frame for the data infrastructure including web-based catalogue services have been developed for better data handling among partners (e.g. Geo-referenced data sets). A GIS based Data Management System has been developed that is composed of a) the meta-data reporting system, b) the search and discovery system (clearinghouse mechanism) and c) a data warehouse.

- *Sensitive regions and case study-regions:* A European survey will provide the geographic identification and an overview on environmental, economic and social issues in sensitive regions. In addition, a set of case study areas were selected in order to test SIAT through stakeholder involvement for valuating determined impacts. Sensitive regions are categorised in (a) post-industrial zones, (b) mountainous areas, (c) islands, and (d) coastal zones. Information from sensitive regions and case study areas identify common and specific key problems of sustainability.

- *Participatory Processes and Institutional Analysis:* Sustainability issues and the institutional role are analysed to make recommendations for SIAT design. Additionally the SIAT prototype will be tested in real world contexts. Here, ‘society’ is fully integrated into the science of assessment of the sustainability of multifunctional landscapes. The main task is to supply social science expertise including stakeholder analysis, institutional analysis, deliberative processes and quantitative and qualitative social research.

The above mentioned activities are integral components of the meta-model SIAT, which overcomes a purely quantitative impact assessment tools at (macro) economic level, while it is simultaneously extended by environmental and social issues. A major gap existed between macro-economic and equilibrium models of the land use sectors on the one hand, and mechanistic (“systems”) modelling of ecological and social processes on the other hand (Tamborra 2002). Thus, SIAT tries to close this research gap with combining different indicator methods towards a meta-model approach.

On this basis chapter 2 introduces SIAT related to the problem in order to answer the research question of how to cope with the system complexity of SIAT regarding consistency and reliability of scenario outcomes. Following, chapter 2.1 describes the design and functionality of the SIAT system and chapter 2.2 explains the internal levels how consistency of SIAT has been achieved by means of validation processes. Chapter 3 concludes on main findings.

2 Sustainability Impact Assessment Tools (SIAT)

SIAT aims at supporting ex-ante sustainability impact assessment[2] towards an integrated perspective of a comprehensive analysis of cross-sectoral effects of policies related to multifunctional land use in European regions (Sieber et al. 2006 and Verweij et al. 2006). To achieve this, SIAT should meet the requirements desired by end users in the European Commission (EC) and fulfil at the same time current research standards on accuracy. Thus, both, internal processes within the research group and external processes with the contractor organisation (EC) influence the model design.

Current operational tools are compared to SIAT mostly restricted to precise, quantitative sector information on aspects of economic, social or environmental impacts that are mainly designed for ex-post analysis (Bartolomeo et al. 2004). They answer less integrated and comprehensive questions (Tamborra 2002). Integrated ex-ante impact assessment tools are currently strongly requested since also institutional integration takes place among involved departments. This increases at the same time the system complexity, and thus validation and testing plausibility gain importance. The question comes up, whether purely model-driven calculations suffice to produce "sector-limited" results, what kind of methodological extensions are needed to meet the needs of integrated IA and how does this result in what kind of measures to provide a sufficient level of reliability on produced results?

The SIAT integrates in simplifying words 'mathematical functions' as model results of applied system components (macro-economic and sector models). This procedure requires interrelated consistency between linked models, of which only aggregated results as defined solution spaces in the form of response protocols (and not the entire model framework) are integrated into the meta-model SIAT. Hence, first the iterative procedure of linking models to a model framework and secondly aggregating these results imply potential deviances compared to standard-estimations of state-of-the-art sector models. Last but not least non-standard solution finding with complementary techniques (e.g. rules of thumb) increases the uncertainty on reliability.

In order to achieve this under the condition of assuring reliable assessments, the meta-model approach SIAT has been developed. Aggregating diverse types of applied methods of meta-modelling and complex-controllable responses of linked system components increases the system uncertainty for accuracy and reliability on results. A major challenge of the current project phase is ensuring a commonly accepted level[3] of reliability of the complex meta-

[2] Ex-ante sustainability impact assessment is an obligatory process to be conducted when new policy proposals are under policy discussion and a major requisite towards the fulfilment of the European Sustainable Development Strategy (EC 2001, EC 2005). The European Commission presented an Impact Assessment process (IA) that consists of 6 steps in the European IA Guidelines (EC 2005). Within this IA procedure the developed Sustainability Impact Assessment Tool (SIAT) covers step 4 and 5: the analysis of policy options, the assessment of the divergence to defined objectives and the comparison of policy options.

[3] A „commonly accepted level of reliable results" is defined as a broad acceptance by an expert panel of the SENSOR-research group and result finally in a satisfying response of major end user groups.

modelling. Taking the above considerations into account, the following chapter explains first the model design and functionality of SIAT and subsequent discusses in chapter 2.2 the needs and processes for system validity and plausibility of the meta-model system.

2.1 Model definition, design and functionality

SIAT enables simulating policy instruments that affect land use across the six sectors agriculture, forestry, energy, transport, nature conservation and tourism. It provides cross-sectoral trade-off analysis for long-term land use changes at a regionalized level of the EU 27 plus associated accession countries. The ex-ante impact assessment with SIAT aims at simulating EU-policy proposals mostly summarised in green and white papers of the EC. The set of simulated policies ranges from non-monetary (e.g. the EU soil directive) to monetary instruments such as taxes and subsidies at a fairly aggregated level as bundles of single instruments (e.g. subsidies to promote renewable energies). The effects are projected in administrative NUTSX-regions that stand for a harmonised schematisation between NUTS 2 and NUTS 3. Each scenario is solved by comparative-static analysis, while reference scenario results (based on assumed global economic, demographic and policy trends) and policy simulations results of the same target year 2025 are contrasted by a set of 45 multifunctional indicators.

SIAT conducts quick-scan analysis and operates at three main analytical levels. At a first level the (a) multi-functionality approach[4] assesses the impacts of the cross-sectoral effects of introduced policy variables. At a second level the (b) sustainability approach compares indicator results with introduced critical limits as thresholds and targets. The thresholds are defined as science-based tolerance limits, whereas the targets are considered as policy-driven objectives. Both are computed for clustered problem regions that reflect the same biophysical and socio-economic profile with a similar multi-criteria profile. The third level (3) re-aggregates sets of single indicators that are categorised according to regional sustainability issues to spatially explicit land use functions (Luf). Luf cover the environmental dimension (abiotic and biotic resources including soil, water, air, biodiversity), societal dimension (social welfare, gender equity and migration, cultural heritage, recreation, aesthetic issues) and the economic dimension (employment, growth). The LUFs indicate the provided region-explicit level of 'goods and services' (Helming 2007).

The SIAT follows two main modelling-related principles: transparency and back tracing. Transparency means that all calculation steps are explained by fact-sheets on indicator calculations and underlying assumptions with encompassed reliability information. With back tracing actual computations of impacts can be backward analysed to their drivers to understand explaining factors' contributions of the region-explicit impacts including information on the

[4] The theoretical concept of multi-functionality has been developed as one key approach to implement sustainable development in the area of agriculture and land use (Cairol et al. 2005). In this regard multifunctional land use is intended to integrate social, economic, and environmental effects simultaneously and interactively within the set of all observed land use actions. Based on the multi-functionality concept, SENSOR aims at synthesising assessment approaches for all three sustainability dimensions with quantitative tools where possible.

uncertainty bounds. Hence, transparency of knowledge is guaranteed by (1) offering all implicit knowledge and (2) explicit back tracing of the knowledge used during calculations.

Policy cases represent thematic areas and they consist of sets of specific policy instruments. The intensities of introduced policies are to be translated into respective sectoral land use changes related to subsequent sustainability impacts. Impacts are expressed in social, economic and environmental indicators. Thus, the dual approach of SIAT (1) assesses the functional correlations between the introduced policy variable (policy response functions) with intermediate variables (e.g. land use change). This correlation is translated in a second step (2) by estimating the functional relation between intermediate variables and indicator values (indicator functions). Each indicator function describes the region-explicit behaviour between the shift of intermediate variables (e.g. land use change, number of animal etc.) and the corresponding response of the indicator variable (see fig. 1).

For each policy case a separate set of six response functions (each represents one sector) for each of the 473 regions is derived by the specifically developed model framework. One response function describes thus the behaviour between the intensity of a policy instrument related to corresponding land use change (or intermediate variable) for one sector in one of the 473 NUTSX regions. Each function describes *all* possible correlations between policies to land use claims in a continuous way (see fig. 1 upper diagram). The applied assessment procedure varies the intensity of the simulated policy until sufficient sets of correlations between policy levels and respective sectoral land claims are available. Having shifted the policy intensity by applying this procedure, at least five point estimations should be available. A set of five point estimations[5] suffice to assess by means of econometric methods one mathematical response function.

In order to assess the above described response functions, the modelling framework interacts among linked components as follows: First, macro economical modelling is carried out by NEMISIS (Kouvaritakis 2004) in sectoral division for respective administrative regions. NEMESIS safeguards the statistic accounting frame and allocates needed sectoral demand-driven land by means of specific allocation algorithms. Based on the macro-economic agricultural and timbered land claim, the sectoral models CAPRI (Britz et al. 2003) and (partly) EFISCEN (Lindner et al. 2002) determine intra-sectoral interrelations and feedbacks land prices and physical land claims to the macroeconomic sector level. Thus, feedback loops between the macro- and sectoral models assure model-specific equilibriums on prices between macro-economic sector output as land allocation and internal sector land use claims. The consolidation of the model framework is reflected in equilibrium prices and physical supply-demand equilibrium for goods and services related to land allocation. In order to assess land use related impacts these administrative modelling results are disaggregated to grid level (1x1 km) using the CLUE model (Kok et al. 2000). Consequently, land use modelling is done on

[5] The point estimations are symbolised by grey point along the assessed function of the upper diagram (see fig. 1).

this grid based schematisation. Finally these grid based results are aggregated to the administrative regions of impact projections.

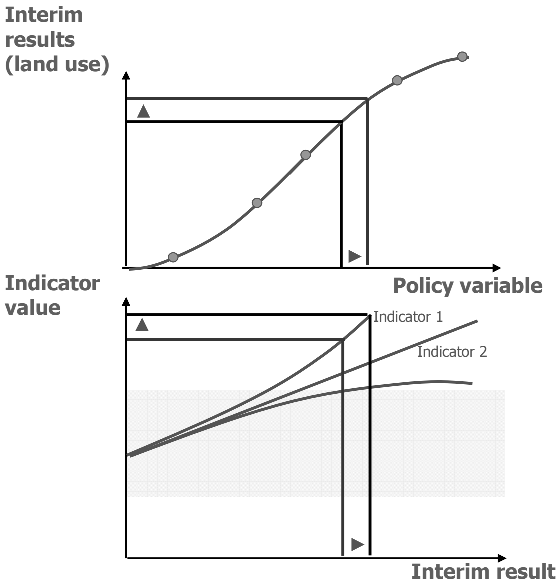

Fig. 2.1-1. Dual approach of policy and indicator functions in SIAT

The advantage of this meta-model concept lies in a short response time. Thus – and due to the continuity of solutions by the given response protocols – SIAT can be re-used continuously in wide range of iteratively applied scenarios; individually or in group decision rooms. Current estimations calculate a response time of less than 2 seconds per simulation. To link different model components within SIAT the Open Modeling Interface standard (OpenMI) is used (Gijsbers et al. 2002). The use of this standard increases efficiency and minimises the risk of system development (Wal et al. 2003). At the same time it ensures compatibility by wrapping different calculation methods with standardised software of linkable components.

Not all considered indicators are covered by the quantitative modelling and need therefore alternative calculation methods. They can be described as quantitative or qualitative knowledge rules (rules of thumb). Quantitatively and qualitatively described relations use rules of thumb similar as decision trees in dependence of fuzzy logic-techniques. These rules are generalisations of complex processes applicable in specific circumstances (see fig. 1).

Standard SIAT interface and fact sheets

The standard SIAT design of the first prototype divides the user interface into four differently sized rectangles, which is continuously stable while navigating through various linked layers (see fig. 2). The major objective of prototyping is the communication of possible designs including underlined concepts of specifically developed procedures of solving policy scenarios.

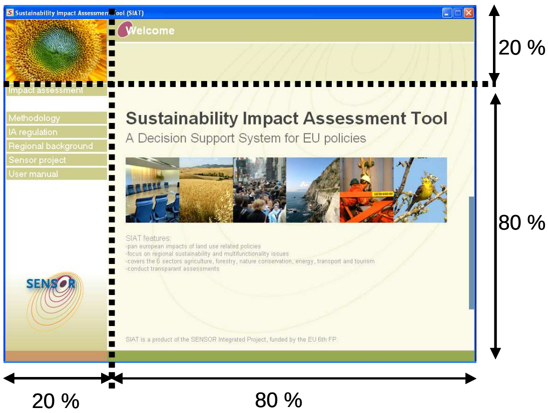

Fig. 2.1-2. : General design of SIAT

Specific fact sheets consist of (1) opening pages of each category that summarise the specific topic and serve as an introduction, (2) sub-categories as summary reports that emanate from different sources as deliverable reports, existent other reports and modules' contributions, (3) fact sheets on specific qualitative indicators giving region-explicit information on the result, knowledge rule and inter-linkage on causal chains and (4) summarising the assumptions for definition the reference and policy scenarios.

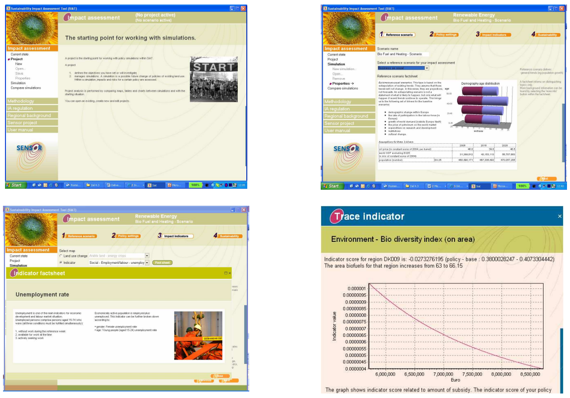

Fig. 2.1-3. 4 fact sheet categories - t.l. area-wide, t.r. embedded, b.l. new frame, b.r. tracing

Applying Policy Simulations

The SIAT lays emphasis on simulating future scenarios. As the concept of solving policy scenarios is the core of the meta-model, the step-wise *procedure* was essential part of the first prototype. According to current results, a complete scenario comprises five steps: defining the (1) reference scenario, (2) policy settings and analysing, (3) impact indicators, (4) sustainability risk and (5) land use functions.

The first step (1) defines the macroeconomic reference scenario to compare results of different policy simulations. The results of these reference scenarios are projected to the target year 2025 to be able to identify the impact of the policy scenario results. The three reference scenarios business as usual, high-growth and low-growth assume positive and negative anticipated trend-estimations of the incorporated land use drivers, oil price, R&D-expenditures, technological developments, demographic changes and global economic changes. Step number (2) is the definition of policy measures expressed by policy settings within each thematic policy case. The user can define the intensity of policy simulations within pre-cooked sets of given ranges. Step number (3) illustrates the impacts of the introduced policy variable that is presented in interactive maps, tables and graphs. Photorealistic visualisation underlines the result expressions. Step number four (4) conducts the risk assessment by quantifying the deviation of impacts and region-specific critical limits. (5) Step number five aggregates single indicators through specifically developed scoring systems towards Land Use Functions (Luf) that indicate the level of goods and services at regional level (Helming et al. 2007). By simulating iteratively sets of shifted policy intensities, multiple scenarios can be compared among each other through amoeba type diagrams. In all nine LUFs as specific indicator aggregation are part of the scenario analysis ‘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’, ‘Support and provision of habitat’ and ‘Maintenance of ecosystem processes’ (Helming et al. 2007).

Demand-oriented design

The further development of SIAT depends on end user requirements. Iterative involvement of potential end users of SIAT during the development process of is a key requisite to success. Potential end users are involved during the development of SIAT through evolutionary prototyping (McConell 1996). Permanent and iterative end user involvement shall assure a broader acceptance of the SIAT approach. In this regard three potential user groups have been identified: (1) The end user at the level of the EC that is at the same time key contractor. The user group at this level are the desk officers accompanying decision making processes. (2) The joint research institutes of the EU (e.g. JRC) provide decision makers with direct information on model analysis. (3) The numerous consultancies that are important potential clients for accomplishing Impact Assessments.

2.2 System validity and plausibility

As explained, the innovative concept of the Sustainability Impact Assessment Tool SIAT is the integrating character of a wide scope of gathered knowledge into one meta-modelling application. This efforts internal integration processes to be conceptualised and steered in an efficient way. The knowledge to be integrated differs in its characteristics and reliability, which requires different techniques of knowledge integration.

Processing of precise quantitative data is always preferable, but in many research fields specific indicators and thresholds are still not unconvertible to concise quantitative assessments. Therefore, SIAT uses a three-stage concept that allows a comprehensive integration: The (1) integration of large-sized quantitative data across European regions derived from the model framework (see p. 5 onwards), (2) complementary integration of knowledge by rules and causal chains between indicators, (3) applying up- and downscaling methods for aggregation of indicators to keep the internal consistency at multi-scale level.

SIAT is generally regarded as an abstraction of phenomena of the real world, while a meta-model is a further abstraction that is highlighting properties of the model itself (Pidcock 2003). Since SIAT combines different individually developed model components and expert knowledge, validity and plausibility are major challenges to illustrate complex correlations that are not comprehensible by heuristic expert judgement without modelling.

In order to achieve overall consistency of such a complex model system consisting, a wide range of processes for calibration, validation and plausibility checks are applied at various levels throughout the duration of system development. The term ‘overall consistency’ can be interpreted as a process chain of measures to obtain reliable results of policy simulations as consistent behavioural response based on made assumptions. In the following the chain of processes for system consistency are described:

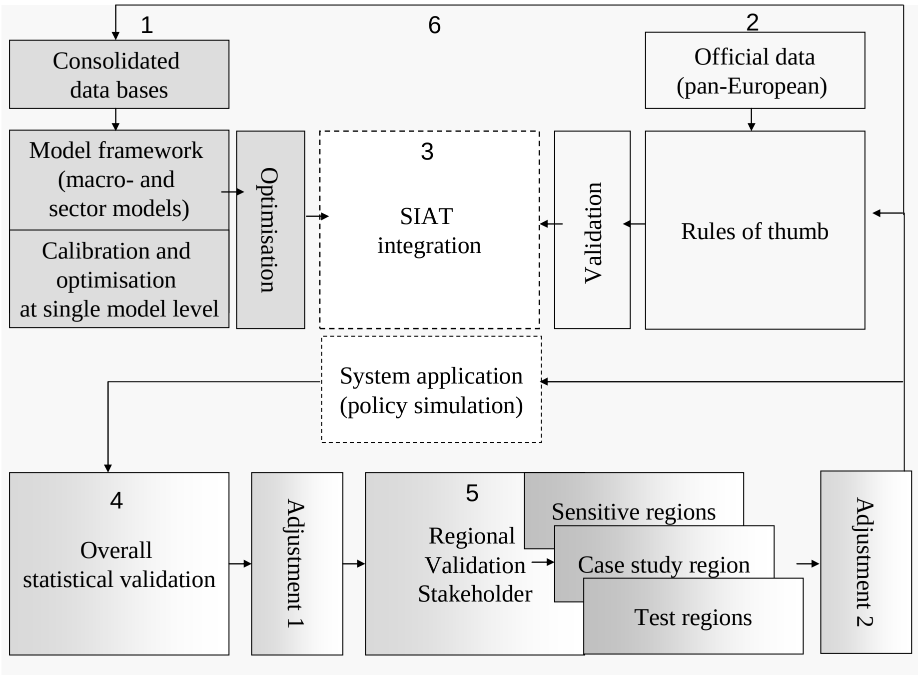

Fig. 2.2-4. Process chain of continuous advancement of system consistency within SIAT

Figure 4 illustrates the different levels in terms of (a) consolidating model components for SIAT integration to be able to run policy simulations and (b) processing the validation chain towards testing the reliability and plausibility of results. In this regard figure 4 illustrates the process of the applied validation chain that is described in the following main steps:

- Step 1: Each model that is used within the model framework was developed in long-term perspective and thus consists of consolidated data bases. Due to the fact that single models had to been adapted specifically for SENSOR, calibration methods have been applied newly for each used model. Resulting, at the level of single sectoral and macroeconomic models, consistent data bases and calibrated algorithms on optimisation are available.

- Step 1: Linking these models within the framework implies ensuring overall optimisation towards consistent results across macro-economic and sectoral level. Since equilibrium land prices related to physical land use claims are achieved among macro-economic and sectoral models, the model-model optimise macro-economic supply and demand towards sectoral land use allocation (see quantitative optimisation below).

- Step 2: If indicators are not derivable from the model framework, rules of thumb as decision trees are developed separately. This effort knowledge rules to be implemented into SIAT that internally has to be consistent in terms of plausibility and to statistical data. Each knowledge rule has to be validated to the quantitative outcome of the model-framework in terms of multi-scale consistency as well as relative indicator scoring (see qualitative assessment validity).

- Step 3: The integration of quantitative and qualitative methods efforts applying aggregation methods on up- and downscaling as well as internal technical compatibility, which is to be supported by the OpenMI software. OpenMI allows easier handling of adjusting and setting input-output relations between linkable components within SIAT (see overall multi-scale consistency).

- Step 4: Having applied the SIAT model, checks on plausibility and continuous adjustments of the development team takes place. This validation phase screens all indicator outcomes towards internal consistency of the applied indicator methods and checks the results comparatively among indicators on reliability and plausibility.

- Step 5: Different expert teams within SENSOR judge the reliability and plausibility in terms of specific site conditions as well as randomly selected test regions. Latter contrasts the SIAT results by applying heuristic statistical analysis, whereas sensitive regions take into account specific site conditions to query plausibility in detail with in-depth analysis on local characteristics. Overlapping case study regions involve local stakeholder to acknowledge the relevance of provided local land use services as well as predicted regional results (see specific regional plausibility).

- This above described process is interactively conducted. Subsequent to adjustment 1 and 2 feedback loops correct either the implemented knowledge rule of indicators or approximate the model framework towards plausible results. These adjustment processes is posed as overall iterative loop until the optimised matching between outcomes of the system complexity (SIAT), externally involved stakeholders and internally participating expert groups is reached by means of appropriate sets of Delphi-processes.

Since most important components are quantitative modelling, qualitative knowledge rules on indicators and validation though stakeholder involvements at regional level, these aspects are described in the following chapters in detail.

Quantitative optimisation

At this phase of internal integration of sets of models within the model framework, quantitative information is regarded as the systematic scientific investigation and forecast of land use policy related quantitative properties and phenomena and their relationship via macroeconomic and sectoral models. Mathematical models, theories and hypotheses pertaining to land-use related phenomena are to be further developed and employed in order to integrate this quantitative knowledge. The process of measurement, i.e. achieving outputs as numerical response protocols, provides fundamental connections between empirical observations, forecasts and the mathematical expression of quantitative relationships. Hence, quantitative response functions have been directly derived from the model framework consisting of macroeconomic and sectoral models. The procedure of linking mode components in terms of optimising and validating response functions is explained in the following (see also explanations of figure 1).

The SIAT model framework is composed of a series of models interacting in a consistent way. The macroeconomic model NEMESIS (Kouvaritakis u. Zachariadis 2004) translates the five drivers population growth, demographic structure, labour force participation, world demand, energy prices as well as the expenditures on research and development into certain scenarios for macro-economic variables across the six land use sectors. Supplied by the NEMESIS results on Gross Domestic Product and regional projections of land prices and physical land at sector level, the land-use model CLUE-S (Verburg u. Overmars 2007) simulates changes in land use for 1 km² grid cells covering Europe. Both of the models communicate sequentially with five models concerning the different priority sectors, namely CAPRI (Wieck et al. 2003) for the agricultural sector, EFISCEN (Lindner et al. 2002) for the forestry sector, TIM for transport and infrastructure, B&B for the tourism sector and SICK for the urban sector. A set of variables stemming from sector models (e.g. CAPRI), feed their results back to NEMESIS and iterate until convergences on prices and physical land units are obtained. All these simulation models allude to an entirely defined set of model results for each of the pre-defined policies under each baseline assumption. Together, these model outputs form an implicit function, which outlines the cross-sectoral response to policy changes.

In general mathematical terms the needed functions can be expressed in a simple correlation between *A* that is the space of possible policies and baseline scenarios, *B* defined as the space of possible model results and *C* considered as the space of possible indicator results (Jansson 2006). Because each model results are unique for each policy and baseline scenario, the model framework implicitly defines a function *f* from *A* to *B*. Furthermore, each indicator consists of a rule or equation that is a function g_i from *A* and *B* to *C*, with subscript *i* indexing the individual indicators. Those assumptions result in

$$f\colon A \rightarrow B \text{ and } g\colon A \times B \rightarrow C \qquad (1)$$

with *f* ss the implicit function jointly defined by the simulation models and $g = (g_1, g_2, \dots, g_i, \dots, g_n)$, where n is the dimension of C (the number of indicators) is called the vector of *indicator functions*. The model user requires the indicator results as a function of policy, which can be computed as $h = g \circ f$. The symbol "$\circ$" is the composition operator, so that for some policy x in *A*, the result of $g(x, f(x))$ is preferred. Intermediate results of *B* are only important on land use change, so generally SIAT is looking at $h\colon A \rightarrow C$).

The implicit function *f* is complicated to assess, because it reflects the joint behaviour of all used models. Some indicator functions are sophisticated to calculate, if they depend on land use grids. The correlation can be qualitatively categorical or quantitatively continuous. They can be simple arithmetic operations on a few model variables or discrete functions pointing to a category or ordinal result. Due to the complexity of the function *h*, SIAT approximates $h = g \circ f$ with some functions η. Letting "≈" mean "is an approximation to", the following two approximations are considered: either $\eta = \phi \approx g \circ f$, meaning that the whole composite function is approximated, or $\eta = g \circ \phi$ with $\phi \approx f$, i.e. only the implicit function f is approximated. The vector of functions ϕ is called "response functions". This means each indicator can be modelled either by a direct link between the policy variable and indicator variable, or in two steps using model results like land use change as an intermediary.

For SIAT both linkages are allowed and used to compute indicators, either with functions of a large number of model variables, linear or non-linear and in the form of a single value or a vector. In many cases indicators are computed as a post model exercise, using but at the same time simplifying existing sophisticated model algorithms. The approximation by meta-model concepts (response functions) substitutes complex computations and accelerates herewith the response and calculation time. Since this model concept is novel, there is no theoretical foundation behind the response functions, but for each model result variable, the entire modelling chain is approximated by a general flexible form with a small set of parameters. Only a limited number of simulation experiments form the base for the estimation of the response function, and thus a second or third degree polynomial is suffice in most cases to hit the few observation points very closely. In many cases, the admissible policy space is *discrete*, i.e. there is a fixed number of available options, where it makes no sense to evaluate a policy that lies "in between" two alternatives. A binary example would be to implement directive d_1 or d_2, where there is no sensible option in between. In that case, *each* possible policy alternative is simulated and the response function has then k parameters $\theta_1, \ldots, \theta_k$ such that, denoting the policy instrument (the implemented directive) by $x \in \{d_1, \ldots, d_k\}$, the response function is given by

$$\phi(x) = \begin{cases} \theta_1 : & x = d_1 \\ \vdots & \vdots \\ \theta_k & x = d_k \end{cases} \qquad (2)$$

This is extended to combinations of discrete and continuous policy variables using (say, x and y) by defining a separate continuous response function for each specific discrete option,

$$\phi(x) = \begin{cases} \phi_1(y) : & x = d_1 \\ \vdots & \vdots \\ \phi_k(y) : & x = d_k \end{cases} \qquad (3)$$

Summarising, each of the quantitative sustainability indicators consists of a direct model output or a mini-model, which is fed by land use change and/ or another models' output. For the information transfer into SIAT, the modellers assessed response functions that (a) describe the correlation between a policy variable and the land use (or interim model results) change and subsequently, (b) express the relation between the land use change (or interim model results) and the quantitative sustainability indicator variables or (c) link policy variables directly to indicator variables. As a result, a reliable set of numerical "response protocols" is provided at regional level of NUTSX. To ensure consistency across different spatial scales, up- and down-scaling methods are applied (see overall multi-scale consistency below).

Qualitative assessment validity

Unlike precise quantitative knowledge integration mentioned above, qualitative information depends on logical reasoning of cause and effect behind diverse aspects of behaviour. Qualitative knowledge develops overall understanding of structures and their systemic behaviour. Qualitative information can be integrated, if the necessary quantitative information is not available. This requires construction of the missing knowledge on causal cause-effect chains between policies and indicators, and ultimately the response and indicator functions associated (see figure 5). Since some of the knowledge integration into SIAT is carried out through response functions, the qualitative inter-correlations have to be subsumed in those functions. In view of the fact that for many cases (particular social science) tangible data is often lacking, it is not possible to define response functions for qualitative information properly based on scientific literature review. For those cases, the Delphi-methods have been applied.

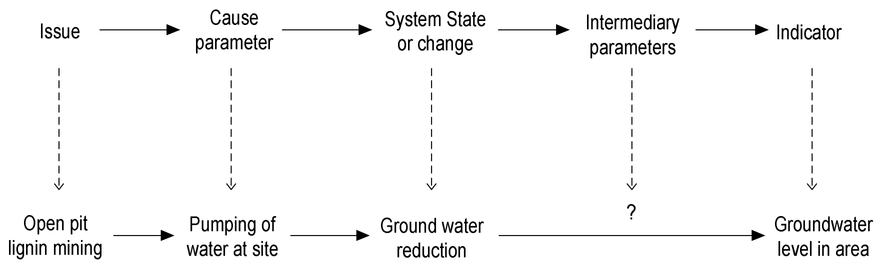

Fig. 2.2-5. Ground water-causal chain translated into an indicator (adapted from Sverdrup et al. 2007).

The Delphi method is a systematic and interactive evaluation method to generate scenarios and make prediction for difficult problems and relies upon independent inputs of selected experts within the consortium (Adler and Ziglio 1996). This is done in accordance to group-modelling techniques developed by Vennix (1996). When full scientific knowledge is lacking, limited information in form of expert opinion, experience and intuition can be used to focus on an agreement on certain behaviour of response functions. The theoretically gained knowledge on found correlations is technically to be translated into knowledge rules that are embedded in coded linkable components.

Decision trees in accordance to fuzzy-logic techniques enable a conversion of conceptual issues through causal chains into a functional variable, which is wrapped by linkable components (see fig. 6). Each linkable component is integrated into the meta-structure of SIAT that allows docking with interfaces of quantitative response functions as output of the model framework.

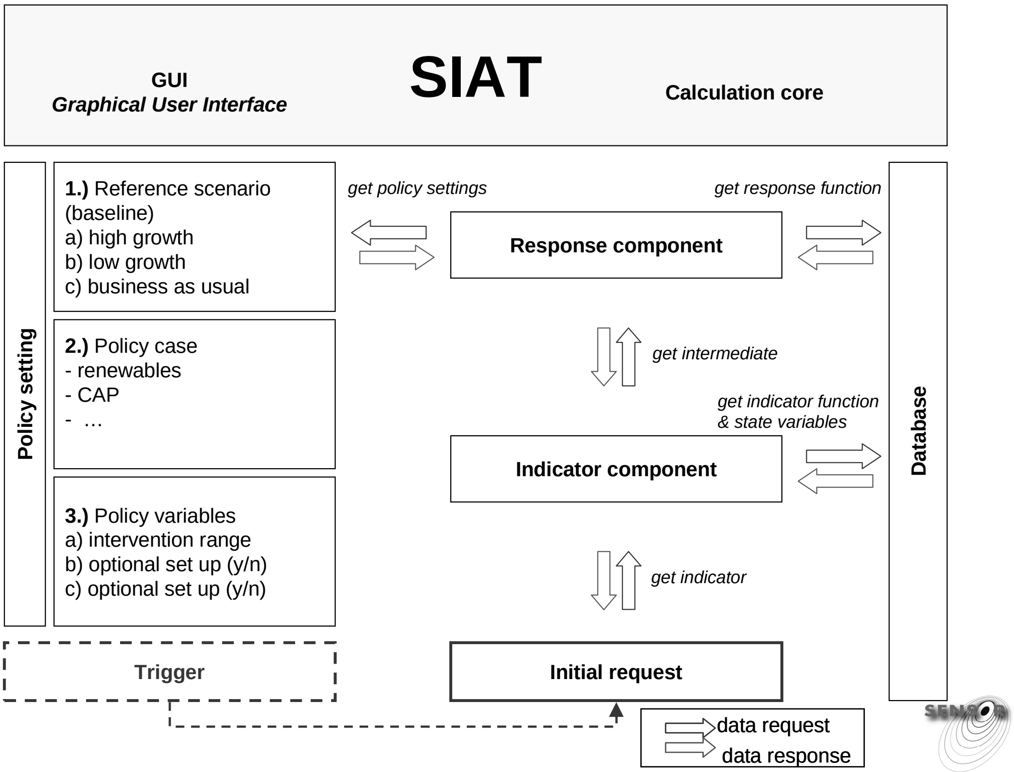

Fig. 2.2-6. Standard schematisation of linkable components within SIAT (Pohle 2007).

Figure 6 illustrates the functioning of a generalised linkable component. The user set specific actions and chooses one of the three available options a) high growth scenario, b) low growth scenario or c) business as usual. Subsequent, specific policy cases provide a set of policy variables. The user adjusts either the intensity of the policy variable within a given range or selects one of two available options. Once the settings are defined, the process follows a determined procedure:

- Processes and pathway (program): Starting point is the initialization of a run that is deployed by the ‘Trigger’.
- The IndicatorComponent fetches the intermediate results to calculate the indicator values in the form of sending data requests via getValuesHook()* to the ResponseComponent that calculates the intermediate data. “*getValuesHook” is considered as one function of a linkable component that requests data from previous linkable component in the calculation chain. Each composition needs a trigger to start the process running, assuming that a composition is defined as a set of linkable components including their connections.
- The ResponseComponent receives information from policy settings (baseline, policy case, policy variables it gets from GUI) and response functions for calculation of intermediate data.
- The Response component calculates intermediates with the gathered data that is fetched from the general database and GUI to be sent subsequently back to the indicator component.

- The Indicator component requests indicator functions and – depending on the indicators method - also state variables to calculate indicator values.

Resulting, each indicator is calculated by indicator components, which are embedded in the system and linked to the protocols on the quantitative calculations (response functions) of the model framework. The indicator method itself is validated by defining and testing through sensitivity analysis, although the consistency and compatibility to the embedded system to the quantitative model outcome can only be tested by applying scenarios. Hence, to validate this system experts groups need to analyse ex-post the reliability of results iteratively, until once internal agreements of appraisals is reached among experts.

Overall multi-scale consistency

The third phase of the validation process focuses on overall consistency of structure and data. An increasing body of literature has developed on the quantification of the sustainability across different sectors. Usually, this literature promotes the idea of monitoring a range of sustainability indicators recognising that sustainability cannot be condensed into a single definition (Pannell and Glenn 2000). Most of these indicators are strongly ecological in focus and very detailed, or they are policy oriented and developed at aggregate, sector or country level. So, indicators are developed that differ greatly in information content and condensation of this information. Scientists are most interested in uncondensed data that can be analysed statistically. Policymakers and the public in general can be assumed to prefer condensed data related to policy objectives and free of redundancy (Pacini et al. 2003). In terms of achieving overall consistency on single indicators, the following SIAT requirements are considered:

- Transparency of processing methods of indicators
- Effectiveness of indicator results’ presentation tools in terms of condensation and non-redundancy of information
- Possibility of aggregation of indicators on different spatial scales, sustainability themes and land use functions in order to get quick scan answers at different levels
- Holistic approach
- Possibility of performing sensitivity analyses of main parameters

Within the framework of numerical presentation there are different ways to present results that depend on the level of aggregation of indicators. Using composite indicators (or indexes) allows for an overview of sustainability (Segnestam 2002). Graphs such as spider diagrams and trade-off curves are very effective and often used in reporting (see e.g., Vereijken 1999, Nicholls et al. 2004). Antle, Capalbo, and Crissman (1998) suggest trade-offs between various dimensions of sustainability as a transparent method including appropriate balancing by giving weights (Weersink et al. 2002). Pannell (1997) considers simple approaches to sensitivity analysis related to trade-off curves as best solution.

However, the Impact Assessment guidelines (EC 2005) give the clear indications to evaluate the policy options as follows: The results should (a) weigh-up the positive and negative impacts for each option, (b) be displayed aggregated and disaggregated results, (c) be compared between options by area of impact (economic, environmental, social) and (d) be identified where the option is preferred.

What above reported means that SIAT should include some method to rank the options by groups and/or by sustainability dimension, and this implies the possibility to aggregate indicators and supply end-users with results to address trade-offs. In this regard the SIAT internal consistency requirements include

- Conceptual and data consistency between impact assessment (IA) issues, land use functions (LUFs) as highest aggregates and relevant single indicators
- Consistency between the macroeconomic, top-down approach and the regional, participative, bottom-up approach

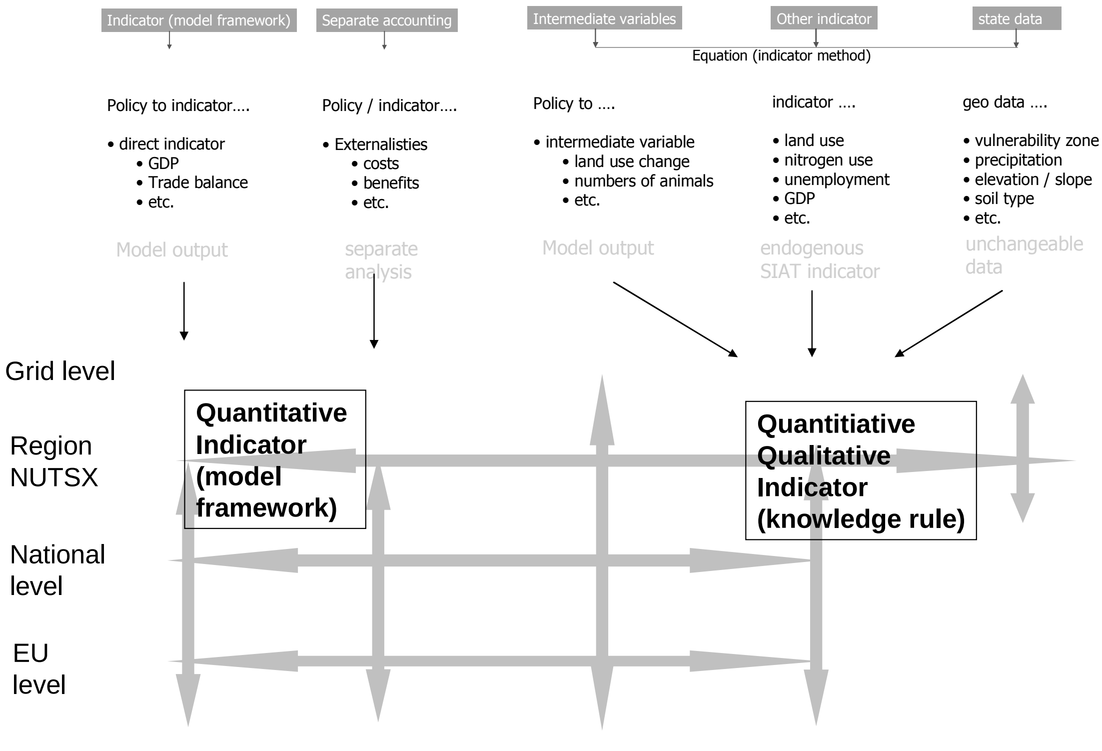

Fig. 2.2-7. Overall consistency across different scales depending on indicator sources

Figure 7 summarises the overall schematisation of consistency requirements on indicators depending on used data sources. The grey arrows indicate the consistency conditions across different scales and aggregation among single indicators. The upper row illustrates all indicator sources, whereas the quantitative indicators (model framework) stem from either direct model output or from separately established accounting framework on externalities. Direct indicators as outcome of the model framework can also be used to build knowledge rules for quantitative or qualitative indicators, apart from additional sources using either intermediate variables (e.g. land use change) or state data. Having these general combination possibilities in mind, specific horizontal up- and downscaling methods allow multi-scale consistency to (1) provide consistent up-scaling of indicator at SIAT's projection level of NUTSX towards building land use functions (LUF), which indicate the regional provision of goods and services. (2) Vertically the indicator methods and the related data records have to be consistent across the scales from Grid- up to the EU-level. Although all indicators are presented at the projection level of NUTSX, the internal consistency across all those levels that are indicated with grey arrows are to be assured within the SIAT calculations.

Specific regional (ex-post) plausibility

After having achieved consistency of the complex system SIAT the ex-post validation of policy simulation is conducted. The overall statistical validation safeguards the SIAT developing team by applying heuristic cross-checks on plausibility with subsequent validation adjustments, if apparent deviances from expected results occur. Due to the fact that in-depth knowledge on specific site-conditions and regional distinctions is at this stage not available, three categories of further validation measures are implemented with consequent objectives:

- To develop a consistent data base across all sensitive area case studies (SACS) according to the principles of (a) compiling the data and information in each SACS for at least one NUTS3 cells with regard to the SIAT testing and modelling approaches, (b) accomplishing the available information at disaggregated level within each SACS to systematically increase the level of spatial and temporal details for the exploration of SACS specific indicators. Resulting testing of the dissimilarity between SACS and general European regions takes place.
- To apply a comparative analysis of European wide and SACS specific sustainability indicators in order to test their applicability, limits and constraints according to the spatial resolution. This will add to the bottom up approach and will allow to cross-check the validity of SIAT indicators developed from a top down perspective of NUTSX.
- To develop a methodology and protocol for the efficient implementation of the European Environmental Technology Action Plan (ETAP) for sustainable economic, social and environmental development and for overcoming conflicts between stakeholders and local authorities to which policy is directed.

Summarising, regional characteristics are down-scaled to disaggregated level and compared with the SIAT outcome at the level of NUTSX. The above described actions are supported by stakeholder involvement within case study regions. The process of ex-post evaluations is continuous in order to reveal mismatches between SIAT model results and regional expectations of policy-depending scenarios analysis.

3 Conclusions

The important aspects discussed in this article concern the process of developing the design of model-based DSS 'Sustainability Impact Assessment Tool' (SIAT). Ex-ante sustainability impact assessment of land use-relevant with SIAT aims at integrating cross-sectoral trade-off analysis.

The meta-model efforts non-standard technical solution finding, in particular in terms of consistency between proposed issues of the impact assessment guidelines, single indicators among all observed scales and land use functions (LUFs) as aggregates of indicators to indicate the provision of goods and services at regional level.

Ensuring reliable model scenario results requires a set of calibration and validation processes at various levels of the complex meta-modelling system SIAT. Subsequent heuristic ex-post plausibility testing of sensitive area case studies with stakeholder involvements adjusts mismatches between model results and expectations at regional level.

The complex meta-model system SIAT needs a set of measures to be able to assure reliable results of policy scenario. Potential inconsistencies can be reduced by validating the model framework and individually developed knowledge rules on indicators, but ex-post validation of model results at disaggregated level with stakeholder involvements is at the same time an inalienable and complementary procedure.

The described overarching process of validating SIAT is interactively conducted. Subsequent feedback loops correct either the implemented knowledge rule of indicators or approximate the model framework towards plausible results. These adjustment processes is posed as overall iterative loop until the validated results match between outcomes of the system complexity (model framework), externally involved stakeholders and internally participating expert groups is reached by means of appropriate Delphi-processes.

As SIAT prototype II is currently being developed, scenarios results are not available at this project phase. Hence, experience of the validating process is still missing and evaluating success could so far only be verified on single components.

References

Adler M, Ziglio E (1996) Gazing into the Oracle: The Delphi Method and its application to social policy and public health. Kingsley Publishers, London

Bartolomeo M, Giugni M, 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.

Britz W, Perez I, Wieck C (2003) Mid-Term Review Proposal Impact Analysis with the CAPRI Modelling System, Mid-Term Review of the Common Agricultural Policy. July 2002 Proposals Impact Analyses, European Commission, Directorate-General for Agriculture ed.

Cairol D, Coudel E, Barthélémy D, Caron P, Cudlinova P, 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. 23 pp. www.multagri.net

European Commission (2005) Impact assessment guidelines. SEC791

Gijsbers PJA, Moore RV, Tindall CI (2002) Towards OMI, an Open Modelling Interface and Environment to harmonise European developments in water related simulation software. Hydro-informatics, 2002

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

Kok K, Veldkamp A (2000) Using the CLUE framework to model changes in land use on multiple scales, Tools for land use analysis on different scales. Kluwer Academic Publishers, Dordrecht, pp 35-63

Kouvaritakis N, Zachariadis T (2004) New Econometric Model for Environment and Strategies Implementation for Sustainable Development (NEMESIS), The Environmental Module. Final Report, National Technical University of Athens, Greece

Lindner M, Sohngen B, Joyce LA, Price DT, Bernier PY., Karjalainen T (2002), Integrated forestry assessments for climate change impacts. Forest Ecology Management 162: 117-136

McConell S (1996) Rapid Development, Microsoft

Nicholls CI, Altieri MA, Dezanet A, Lana M, Feistauer D, Ouriques M (2004) A Rapid, Farmer-Friendly Agroecological Method to Estimate Soil Quality and Crop Health in Vineyard Systems. Biodynamics 250: 33-40

Pacini C, Wossink A, Giesen G, Vazzana C, Huirne R (2003) Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. Agriculture, Ecosystems and Environment 95: 273-288

Pannell DJ, Glenn NA (2000) A Framework for the economic evaluation and selection of sustainability indicators in agriculture. Ecological Economics 33: 135-149

Pannell DJ (1997) Sensitivity analysis of normative economic models: theoretical framework and practical strategies. Agricultural Economics 16(2): 139-152.

Pidcock W (2003) What are the differences between a vocabulary, a taxonomy, a thesaurus, an ontology, and a meta-model? http://www.metamodel.com/article.php?story=20030115211223271, (30.10.2006).

Reeve D, Petch J (1999) GIS, Organisations and People, A Socio-Technical Approach. Taylor and Francis Ltd., London

Segnestam L (2002) Indicators of environment and sustainable development. Theories and practical experience. Environmental Economics series, paper n. 89. The World Bank, Washington, DC

Sieber S, Helming K, Müller K, Verweij P (2006) SIAT (SUSTAINABLE IMPACT ASSESSMENT TOOL) - Spatial EU wide modelling of land-use related policies based on new rural typologies, Conference paper on the IPTS-expert workshop, The diversity of rural areas in the enlarged EU: Characterisation, typology and modelling, Seville, Spain

Sverdrup H, Haraldsson HV, Robért KH, Olsson L and Belyazid S, (2007) Deriving operational sustainability definitions and thoughts on how to find indicators. In: Helming K, Tabbush P and Perez-Soba M (ed) Sustainability Impact Assessment of land use policies. Springer, Berlin Heidelberg New York

Tamborra M (2002) Socio-economic tools for sustainability impact assessment – the contribution of EU research to sustainable development. Energy, environment and sustainable development. EUR 20437.1 Office for official publications of the European Communities, Luxembourg

Verweij PJ, Sieber S, Wien JJF, Müller K (2006) SIAT, a Sustainable Impact Assessment Tool for Understanding the drivers in integrated impact assessment. International Conference IEMSS, 6 p,Vermont USA

Vennix JAM (1996) Group Model Building. 297pp, Wiley, New York.

Verburg, P.H., Overmars, K.P (2007) Dynamic simulation of land-use change trajectories with the Clue-S model. In: Koomen, E., Stilwell, J., Bakema, A., Sholten, H.J. (Eds.). Modelling land-use change progress and application. The geojournal library, volume 90. Springer. pp321-338.

Vereijken P (1999) Manual for prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. AB-DLO, Wageningen

Wal van der T, Wien JJF, Otjens AJ (2003) The application of frameworks increases the efficiency of knowledge systems. Proceedings of the 4th EFITA conference on ICT in agriculture

Weersink A, Jeffrey S, Pannell DJ (2002) Farm-level modelling for bigger issues. Review of Agricultural Economics 24 (1):123-140

Wieck, C., I. Perez, W. Britz (2002): Impact Analysis of the Medium Term Review Proposals with the CAPRI Modelling System. Publication of the European Commission.

Wiggering H, K Mueller, A Werner and K Helming (2003) The concept of multifunctionality in sustainable land development. In: Helming K and

H Wiggering (eds) (2003) Sustainable Development of Multifunctional Land¬scapes. Springer-Verlag Berlin Heidelberg New York. 286 pp. ISBN 3-540-00008-9. p 3 – 18.