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Lessons learnt on Requirement Analyses to establish new model systems: Prerequisites to assure model use towards policy outcome

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Abstract: The objective of the paper is to evaluate the applied non-standardised Model Requirement Analysis (MRA). Using the presented methods and results of the MRA, we discuss the suitability for appropriate ways to improve applied methods using the example of the Sustainability Impact Assessment Tools (SIAT). Special focus is given to the prerequisites of project design to assure model use towards model outcome.

The applied methods of the MRA consist of evolutionary prototyping, which provides a way to structure the subsequent group discussions with end-users. The results first summarise the conducted interactions with potential end-users and evaluate the usefulness of conducting MRA for each end-user meeting. A direct outcome of the MRA is the identification of four categories of requirements for the SIAT design: (a) Spatial, time and thematic integration, (b) technical performance and system advancements, (c) quality assurance of data and model systems results and (d) organisational linkages for model system embedding.

We give a number of reasons why the undertaken development process of SIAT was not sufficient for actual operational use towards outcome at the level of policy decision making. A number of recommendations and rules for stakeholder involvement and development methods are suggested in the conclusions.

Keywords: Sustainability Impact Assessment, decision support systems, model use

1 Introduction

Model systems often simulate potential impacts of policy options in order to support decision making (Van Ittersum et al., 2008). There exist still gaps between design and use of model systems (McIntosh et al., 2008). To ensure a high use of model systems among policy decision makers, there is a need for model systems to be aligned to user needs and to overcome the gap between design and use at the science-policy interface (Norse and Tschirley, 2000).

In this paper, we analyse the applied method of a non-standardised Model Requirement Analysis (MRA) using the example of the Sustainability Impact Assessment Tools (SIAT) model system. SIAT was developed in the frame of the Integrated Project SENSOR funded by the 6th Framework Programme of the European Commission, which brought together teams of researchers from 36 institutes in 15 European countries.

SIAT supports integrated ex-ante impact assessments in the context of multifunctional agriculture and sustainable development (Helming et al., 2008). SIAT was designed to simulate land use policies up to the year 2025 at a regional scale of 570 European regions. Its 83 implemented indicators implicitly synthesize the agriculture sector and the related sectors of forestry, tourism, nature conservation, energy and transport (Sieber et al., 2008). SIAT allows for regionalised trade-off analysis of sustainability

indicators and conducts evaluations of sustainability decision choice spaces (Helming et al., 2008).

The objective of this paper is to evaluate the applied non-standardised Model Requirement Analysis (MRA) according to its usefulness for developing SIAT with regard to incorporate the results into environmental policy and management actions. Based on the presented methods and results of the MRA, we give recommendations on improving the process, lessons learnt and prerequisites to assure transition towards outcome.

2 Material and Methods of MRA

This section clarifies the terminology and discusses first the key methods of (a) evolutionary prototyping and (b) prototype-based group discussions with end-users, which have been applied to conduct the non-standardised MRA. Then we classify these methods into the phases of the project design for model evolution.

2.1 Defining the MRA

Among the various MRA methods documented (Wieggers, 2003; Ricca et al., 2007; Araujo et al., 2007), 'user involvement' and 'prototyping' emerge as two key components of MRA (Young, 2001; Sommerville, 2006; Wieggers, 2003).

Software prototyping as a means to guide the model development process should focus the functionalities and model design on the final version of the model, which should be discussed in terms of the specific use of end-user groups (Guida et al., 1999). Typically, certain features mark the functionality of specific domains, which are developed step-wise in collaborative discussions with interdisciplinary researchers (Davis, 1992). Model components require a demand-pull design in their initial orientation (Reeve and Petch, 1999) and may have to use 'socio-technical' methods, such as Soft Systems Methodologies, to reflect organisational needs (Winter et al., 1995). The requirements often focus on functional user interface design (Hu et al., 1999). According to studies, non-functional requirements such as quality criteria seem to be less discussed in requirement analyses. Virzi et al. (1993) discussed intensively the usability problem of applying different types of prototypes.

Group discussions with involved potential end-users are often seen as a complementary measure for prototyping. He and King (2008) have widely discussed the importance of user participation with regard to model systems for decision making support. The selection of potential end-users, either as individuals or groups, highly affects decisions regarding model design (Van Daalen et al., 2002; Vetschera, 1997) in terms of both functionality and architecture (Hemmati, 2002).

In establishing mixed end-user groups, different roles, interactions and applied methods should be analysed preferably by a broad spectrum of participants in order to take into account as many requirements as possible (Checkland and Holwell, 1999). Often a broad and good narrative in discussions is more engaging and useful than the best science (Checkland and Holwell, 1999).

For any existing process of decision-making, the organisational structure of the model use plays an important role in design (Fredman et al., 1999; Aggarwal and Rajesh, 1996). More diverse, cross-departmental user groups may lead to an increase in required support. Internal work processes, specific roles of actors or the fact that decision makers often tend to delegate responsibilities to scientific contractors, such as downstream operators, should be taken into account (Funtowicz and Ravetz, 1994). Specific hierarchies and the degree of cross-organisational use of a given system create different requirements with respect to design (Vetschera, 1997).

The key question of the above given processes is, whether the applied processes of user involvements were sufficient to implement the model system for actual use at the level of the European Commission among policy decision makers. To survey model requirements we applied software prototyping, which also allowed us to demonstrate the model system design and implemented functionalities. The model system-prototype was presented in user group discussions.

2.2 Implementing MRA in project design

To conduct the non-standardised MRA, we embedded the key components of ‘evolutionary prototyping (see fig. 1) (c)’ and ‘group discussions with end-users (d)’ in the project design. The project design involves a procedure of the following development phases to develop SIAT. The individual stages of the project design can be outlined as follows.

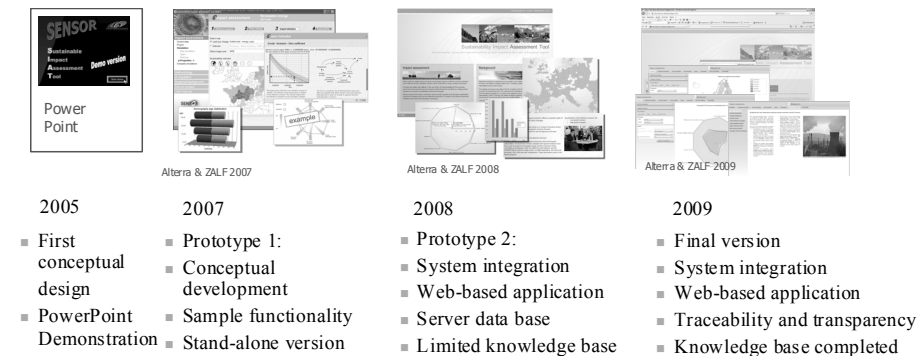


Fig. 1. The evolution of prototype features in the SIAT development process

(a) Basic requirement evaluation

Based on project design, the basic requirements, capacity settings and deliverables were surveyed. The project specifications allowed for broad decisions in fulfilling contract objectives. Feedback surveys with the contracting body served as an effective measure for priority-setting and maintaining continuous communication, thereby ensuring positive support and minimised risk of late negative judgments and evaluations.

(b) Capacity resource utilisation

Reviewing and benchmarking previous in-house endeavours and expertise helped to increase efficiency and minimise the risk of redundancies. This critical review may lead to the re-use of existing software components. Knowledge resources may also be efficiently used or shared among individuals, groups and organisations. The common development of software across research projects, such as visualisation mapping tools, has been realised for the model evolution.

(c) Evolutionary prototyping

Our prototypes provide a way of structuring group discussions. The hands-on prototype contains a Graphical User Interface (GUI) with an exemplary implemented model simulation. As one key objective, the prototype should provide a professional ‘look and feel’ on a range of model functionalities.

The group of developers was composed of natural scientists with different backgrounds, including software engineers, landscape planners and agricultural economists. Subcontracted graphical artists delivered on-demand design elements. The result was a SIAT prototype composed of (1) a user interface, (2) a topic-structure for content management of fact sheets, (3) a simplifying model application for one policy simulation, and (4) a visualisation mapping component. Reliability on simulation results was not significant while continuous feedback on design and functionality served as the input for the second and third prototype.

(d) Prototype-based group discussions with end-users

Mixed groups in our study consisted of software engineers, natural scientists and policy experts as potential end-users. Specifically, major clients such as the Research Directorate General, the Institute for Environment and Sustainability (IES) and Institute for Prospective Technological Studies (IPTS) acted as end-users. The IES and IPTS are part of the Joint Research Centre (JRC) of the European Commission. National institutes and various European institutions were involved in the context of scientific conferences as well as through subsidiary informal interviews.

(e) Organisational analysis using semi-structured interviews

Along with group discussions, semi-structured interviews on organisational requirements were also conducted. Within the project consortium, a different group of scientists was responsible for this research field.

Given the above procedure, we considered steps (c) and (d) key elements of applied non-standardised MRA. Steps (d) and (e) allowed active involvements of potential users of the model. They have to be convinced by prototype demonstrations on the usefulness of the model system for discussion support.

3 Results

The results can be structured in (a) the evaluation of end-user interactions to assess the usefulness of the non-standardised MRA, (b) the relevant requirements as the outcome of the group discussions in the frame of the applied non-standardised MRA and (c) the actual description of the design of the SIAT model system components.

3.1 Evaluation of group discussions

The SIAT developer group was involved in 79 internal and external interactions in group discussions. We note that pre-defined compositions of a stable end-user group could not always be realised due to organisational disposition, which was caused by a lack of permanent members. The open discussions were intended to analyse model requirements, which were focused on *design potentials*.

The evaluation of these interactions was based on available documentation of results and expert assessments. The latter method was implemented by the SIAT developer group using self-assessment to express the usefulness of conducting MRA.

The engagement of the MRA by involved potential end users increased over the project period due to improved prototype demonstrations. The characteristic of the MRA can be described as an outcome of a dynamic group discussion process over the project lifetime. The degree of discussion on model requirements was driven by the given prototype development phases, while the degree of SIAT demonstrations increased due to improved prototypes. Initially lacking discussions on embedding the model system in an organisational structure increased, although it never reached the operational level of actual implementation. While the model design was a stable and central discussion issue, complementary essential issues such as model maintenance beyond the project lifetime and targeted marketing for model promotion were discussed towards the end of the project.

3.2 Results on Model Requirements

The MRA addresses the needs in the context of the evolution of SIAT and they are specifically tailored to European-wide applied policy for IA analysis (Sieber et al., 2008).

The following described profiles for the SIAT model design are clustered according to most relevant thematic fields of requirement criteria. They are the direct outcome of the applied non-standardised MRA and have been revealed in the group discussions. Either available documentation of the discussions (minutes), and major statements of individuals or general discussion foci have been filtered to summarise requirement profiles.

3.2.1 Integration levels for Sustainability Impact Assessment

Sustainability IA requires a high integration of thematically diverse indicators. End-users expressed the need for thematic integration across social, economic and environmental impacts. Analytical requirements necessary to conduct such a trade-off analysis include spatial scales with a high regional disaggregation. Results should be presented at all available spatial scales from local to regional, and national to EU level. Multiple sector perspectives should be integrated, provided that specific sectors are relevant for the analysis. Cross-sectoral trade-off analysis demands the synthesis of sector analyses and should be considered complementary to in depth sector-specific analysis. The number of indicator variables should be balanced over thematic dimensions. Information should only be explicit if it improves the reliability and plausibility of the results.

3.2.2 System performance

Databases are a key technical requirement, that is the most up-to-date, consistent and consolidated databases. The use of European and official data records was considered the minimum standard. Expert judgment shall be allowed to close eventual data gaps, provided estimation methods are analytically sound and well documented.

The response time for computations of scenarios provided a comparative advantage to existing macro and sector approaches. Thus, it was necessary to have a specific model concept, which allowed for a technical default of scenario calculation time of up to one

minute. The emphasis on multiple mapping and visualisation components required non-standardised technical solutions. A basic compatibility among all implemented model system components was required. Overall, these requirements present technical bottlenecks in the software architecture and model components.

3.2.3 Quality assurance of data and model system results

The reliability criteria emphasise the comprehensibility of scenario results and provided statistics. These quality criteria could be categorised as quality criteria on assumptions, measures to ensure transparency and tracing of calculations.

Criteria on indicator results are expressed in group discussions in the form of available causal chains and process knowledge of indicators, explicitness related to illustrated circumstances of the policy and the availability and visibility of the data records used. Furthermore, it was considered important to use evidence of indicator aggregation rules and input-output relations for all observed scales as well as accuracy of veracity (rather than reproducibility) as average accuracy on a given scales. Slightly less importance was given to the accuracy in predicting the results (or correlations) in the future compared to alternative measures. The complexity of results was seen as an unavoidable reality, but the access to information on context and interrelations in defined systems presents a disclosure condition at all output levels.

Transparency requirements should indicate all defined assumptions that determine results at all levels of scenario resolution, including data sources, exogenous scenario assumptions, indicator definitions, calculation rules and causal chains regarding interdependencies among indicators. Explicitness regarding results is necessary, but if implicit knowledge is applied then access to background information should be guaranteed. Flexibility when choosing the depth of required information is important.

Specific tracing techniques should allow the convergence of simulation results into single calculation steps. The procedure should disclose implemented calculation chains. Not the highest disaggregation of traceable calculation components, but simplicity without losing the overview was requested and considered as essential.

3.2.4 Organisational linkages for model system embedding

An early permanent link to key contacts within the target organisation was considered a requisite for success regarding the acceptability and dissemination of a model. MRAs regarding user requirements should be as specific as possible, especially if individuals in organizations can be persuaded to collaborate with the model system developer.

It was stated that potential end-users should be involved as early as possible. The continuity of interactions with potential end users during the iterative model development phases is a key action to be fulfilled. Concepts on formal engagements to further develop model systems either through project-funding should be taken into account.

3.3 System design

This section describes the SIAT design, which has been developed based on the outlined model requirements in 3.2. We first illustrate the component-based SIAT framework, and, based on this explanation, we explain the methodology and resulting functionalities of the SIAT model system.

3.3.1 The SIAT framework

Fig. 2 illustrates the basic framework from which SIAT. The external model chain framework generates SIAT input in the form of pre-calculated response protocols. These 'policy response functions' describe the effects of exogenous policy instrument changes on (intermediate) endogenous indicator variables, which are implemented throughout as exogenous terms in 'indicator response functions'. Thematically clustered indicators in the LUF-component are normalised and then aggregated to Land Use Functions (LUF) as indices of compounded results. Based on these policy settings, scenario-based simulations are conducted. Iteratively-solved simulation results can be retrieved from a cache to be displayed and compared by means of visualisation means.

The SIAT contains a server-based SQL-data base that consists of either mathematical functions or knowledge rules ("rules of thumb") to describe the relation between the policy instrument and the resulting impacts on indicators. The users choose the intensity of the policy instrument (e.g. percentage of direct support of CAP measures) on the Graphical

Use Interface and results will be calculated to be illustrated in visualisation tools (e.g. maps) or to be retrieved in further tools for processing of results (e.g. Excel sheets). New policy cases can be calculated by the established model framework and be uploaded into the SIAT system.

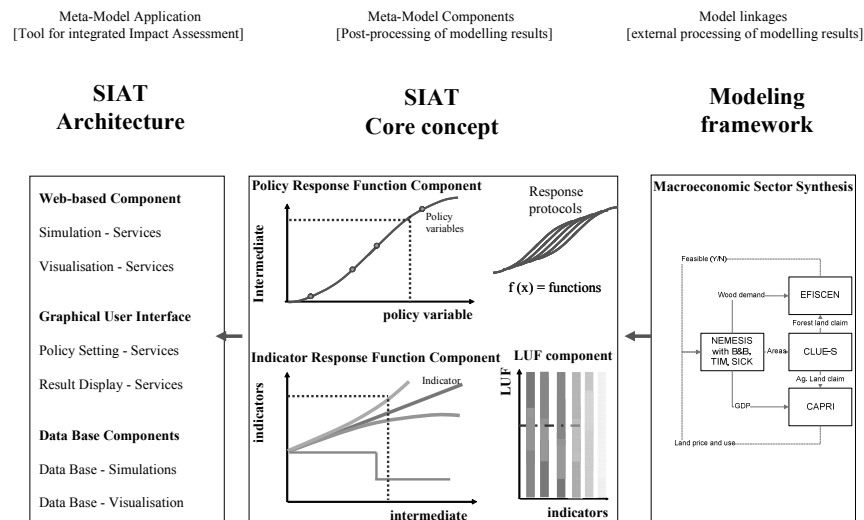


Fig. 2. Component-based SIAT framework

3.3.2 Model chain framework interface

The quantitative results used in SIAT are produced by a system of interlinked models in the model chain framework. It aims to synthesise multiple sectors while maintaining sector-specific details. Each relevant sector for sustainable land use was modelled in detail. The agricultural sector was modelled using the agricultural economic model CAPRI, which runs at regional level within the 27 EU member states (Britz et al., 2008). CAPRI simulates the impact of changing agricultural policies on agricultural production, prices, subsidies and input use (including fertiliser application) in addition to several important environmental indicators, such as nutrient surpluses and greenhouse gas emissions from agriculture. Forest management practices are computed by EFISCEN (Sallnäs, 1990; Schelhaas et al., 2007; Lindner et al., 2002). Based on input data, such as wood demand and forest area, the state of the forest is described using matrices for each forest type in which area is distributed over age and volume classes. SICK, TIM and B&B are models for urban growth, transport infrastructure and tourism respectively. The interdependencies between sectors are handled by linking sector models to an economy-wide economic model called NEMESIS (Zagamé et al., 2002; Brécard et al., 2006) and a land use model called Dyna-CLUE (Verburg et al., 2006). NEMESIS handles competition for production factors, such as land, that are shared among the individual sectors and is also able to simulate the relationship between research and development (R&D) spending and technical progress. NEMESIS also provides results for macro-economic indicators, including employment and economic growth. Dyna-CLUE disaggregates land claims per sector and member state to square kilometres and re-aggregates them into regional scales as required by CAPRI and EFISCEN. Dyna-CLUE also implements spatially-specific policy instruments.

3.3.3 Response function components

The response functions closely replicate the behaviour of the linked system of models and reduce the computation response time. The response functions are static and allow for calculating results within a pre-defined indicator range. The results change depending on the scenario chosen and chosen intensity of the policy instrument (e.g. market support, direct support of CAP measures in percent).

Response functions can be distinguished between indicator response functions and policy response functions. The set of policy response functions for a policy case is generated by performing and analysing simulation experiments with the models, whereas the policy

instruments are systematically varied to cover the entire domain for particular policy cases, with all remaining policy instruments unchanged.

The indicator response function component assures the synthesis of different indicator calculation methods and allows for IA using 83 indicators. Policy response functions provide a linkable component to compute indicators, which are implemented throughout as exogenous function terms in the 'indicator response functions'. This function type transforms the intermediate policy variables into indicators by means of knowledge rules. The indicator response function component results in different types of indicators either by using model output as indications for gross assumptions (i.e., qualitative indicators) or by transforming quantitative model outputs in indicator results with appropriate units, scales and necessary meta-information. The availability of specific and pan-European data was a driving constraint in selecting the actual indicators. Each indicator function requires exogenous sets of variables on specific indicator-relevant information such as state variables (e.g. soil types) and sets of specific intermediate variables, such as land use-change. Indicators can be expressed by quantitative, semi-quantitative or qualitative functions. The value of each observed variable changes depending on the policy settings.

3.3.4 Graphical User Interface (GUI)

The GUI provides users with two pathways, namely, the simulation of policy scenarios using SIAT or the retrieval of background information. It contains a range of functionalities to assure transparency and traceability at user interaction steps along all navigation bars. The SIAT application solves policy scenarios in five steps.

Step (1) computes the macro-economic reference scenario values of the impact indicators for the target year. The reference scenario includes 'business as usual' assumptions, namely, that there will be no changes in terms of anticipated trends of oil prices, expenditures for research and development, the labour force, demographic changes and world economic demand.

Step (2) provides a navigation menu that allows for the selection of policy cases. Each policy case contains sets of policy instruments. Within each case, the user can select and combine different policy instruments. Both the inclusion of one instrument as such and the degree of policy intensity can be chosen in the scenario design.

Step (3) illustrates the computed scenario results of the impact indicators as a consequence of the policy settings. Results are presented using interactive visualisation components such as maps, tables and graphs. Photorealistic visualisations support impressions on changes within landscape views. Map layers using Google data superimpose additional geographical information for specific analyses.

Step (4) evaluates policy impact indicators by means of critical limits, thresholds and targets. These sustainability criteria define sustainability choice spaces, which are based on ex-post scenario comparisons of run simulations.

Step (5) aggregates groups of indicators to Land Use Functions (LUF) that indicate the degree of the relative fulfilment of goods and services at the regional level. Nine LUFs have been implemented, including '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'.

A range of visualisation components have been integrated into the GUI design. They comprise interactive geographical maps, spider diagrams, numerical tables and textual summaries. The logical structures used to retrieve visualisation components in the chain from (a) policy settings to (b) policy impacts to (c) the valuation of policy effects should be self-explanatory.

4 Conclusions

We have applied a non-standardised MRA using the SIAT model system. The research question was, whether the applied outlined methods were sufficient to actually implement the model system for actual use at the level of the European Commission among policy decision makers. Besides the outlined model development process of the SIAT model system design, the following considerations support points of improvements to ensure actual use by involved potential end users as outcome of cumulated actions:

- We would like to state at the beginning that the SIAT model is not currently being used at the level of the European Commission. It was not possible to establish within the project lifetime an entire operational tool ready to utilize for policy advice. The integration of model components is still being processed as post-project endeavour. A workshop to prove the entire implementability with the major aim of demonstrating credibility is being planned for summer 2010.
- Expert analysis of the usefulness of the 79 interactions leads to the conclusion that the SIAT demonstrations and MRA discussions were, in general, effective, while the involvement of a stable end-user group over the project lifetime hindered an efficient *model system embedding* into the organisation structure. The organisational environment to conduct the non-standardised MRA was non-homogeneous and discontinuous among different DIRECTORATE-GENERALS of the European Commission.
- The effectiveness for model success through interaction sessions with end users does not depend on the absolute number of interactions, but the quality of sessions (e.g. well prepared questions on possible options of model features) and the presence of important end users, who has decision rights on model use, are essential.
- The impact of a stable stakeholder group is ideally a targeted model design that maximises the potential use of the SIAT for present end users and their related organisations. These end users pose as catalyser for organisational linkages and model system embedding.

But in order to transform model development to an outcome of actual using the SIAT model system, following lessons learnt and points of improvement should be taken into account:

- Important seems to be a fully operational model system that convinces potential users with an added value compared to traditional already implemented systems.
- A functioning prototype for demonstration is key strategy for convincing operational performance. Feasibility for new implementable model exercises shall be given.
- Permanent and continuous contact office that is well established and ideally is implemented party in targeted organisation (e.g. contact bureau) assures needed reliability.
- Personal contacts at both front end of the target organisation and the providing research centre that last over a long time increases the probability of adoption of new model system.
- The project design should allocate budget for product life cycle and marketing that we consider as important as the model itself. High Transaction costs were a clearly underestimated factor on effectiveness to meet the defined goals.

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