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System for Environmental and Agricultural Modelling;
Linking European Science and Society

Development of a conceptual framework for integrated analysis and assessment of agricultural systems in SEAMLESS-IF

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SEAMLESS integrated project aims at developing an integrated framework that allows ex-ante assessment of agricultural and environmental policies and technological innovations. The framework will have multi-scale capabilities ranging from field and farm to the EU25 and globe; it will be generic, modular and open and using state-of-the art software. The project is carried out by a consortium of 30 partners, led by Wageningen University (NL).

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General information

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Executive summary

The integration of the idea of sustainability within agriculture has been a major item on the European Union (EU) policy agenda and there has been an overall shift from supporting agricultural production towards policies supporting sustainable rural development in a broader sense. However, the complex array of issues related to changes in the agricultural policy requires integrated analysis considering the full set of natural, economic, social and institutional dimensions of sustainability. Analysis and assessment of such complex inter-relationships requires integration of knowledge from different disciplines. The development of an integrated modelling framework (SEAMLESS-IF) has been proposed to support analysis of agricultural systems and assessment of impacts related to sustainability and sustainable development. The present report describes the conceptual basis underlying the development of SEAMLESS-IF.

The report is divided into two parts. The first part describes basic concepts of systems analysis, sustainability and sustainable development, and integrated assessment and modelling that are potentially relevant for the present project. It further reviews the role of indicator, models, scenarios and case studies for impact assessments and provides information about possible technical solutions together with a general introduction into participatory methods including the communication of knowledge.

The second part of the report describes the conceptual basis that is proposed for SEAMLESS-IF to enable integrated analysis and assessment of agricultural systems. Three levels of conceptualisation are distinguished and refer to:

1. delineation of the theoretical framework for analysis and assessment
2. specification of the procedure (workflow) for analysis and assessment
3. model formulation.

The first two levels are initial steps of any integrated analysis and assessment process and are not integrated parts of SEAMLESS-IF per se. SEAMLESS-IF will support and facilitate these activities. The main contribution of SEAMLESS-IF refers to level 3, that is to provide facilities for flexible model formulation depending on the requirements for integrated analysis and assessment of a specific problem.

Key components of the procedure for analysis and assessment have been identified and include:

1. description of the problem by users (user questions)
2. framing the problem (analysis type and procedure, system structure and characteristics)
3. definition of scenarios
4. identification of indicators
5. modelling
6. analysis and assessment (including post model analysis)
7. communication of results

Relationships among these key components including important steps of an assessment process are described in the second part of the report. For selected components initial ideas

about the methodologies used including some of the problems related to their use and implementation within SEAMLESS-IF are presented and discussed. A first description of the underlying modelling concept, i.e. the SeAM model, is provided.

Specific part

1 Introduction

Since the Rio Earth Summit in 1992 the integration of sustainability with agriculture has been a major item on the EU policy agenda, and there has been an overall shift from supporting agriculture towards policies supporting sustainable rural development in a broader sense. The ongoing EU enlargement to the Central and Eastern European countries, the pressure for trade liberalisation and the integration of environmental and other multifunctionality considerations into EU policy have stimulated a review of the Common Agricultural Policy (CAP). The most recent reform of the CAP (IP/03/898, Luxembourg, 26 June 2003) aims simultaneously at improving competition in the world market, improving compatibility with multilateral negotiations to liberalise trade, maintaining viable rural communities, and achieving better targeting of measures designed to address social, environmental and consumer concerns (non-trade issues). Sustainability in farming must be achieved alongside new targets, in related but different policy fields. The EU's environmental policies have gradually changed from a procedural approach ('proscribed actions') to an ambient approach ('achievement of environmental quality targets'). Implementation of the Water Framework Directive, Natura 2000, the Birds and Habitats Directives, the Nitrates Directive, and the integration of animal health and welfare into agri-environmental standards require an integrated action and evaluation at different spatial scales (ranging from detailed local scales up to EU and global scales).

The Common Agricultural Policy of the EU utilises about 40 % of the EU budget, and there are increasing demands for this investment to support the multiple functions of agriculture and to strengthen EU economic and social cohesion. More than ever before, adequate agricultural and environmental policies at EU, national and regional scale are needed that can facilitate agriculture's contribution to sustainable development. Ex-ante assessment of new policies (i.e. assessment before their introduction) is consequently essential to ensure their effectiveness and efficiency.

Past and ongoing European agricultural research has generally been thematic, issue and/or scale-specific, and characterised by disparity of methodological and technical approaches, and hence fragmented. There are clear conceptual disparities between disciplines, both between natural and social sciences, and within each of those major groups of disciplines (e.g. between economics and sociology). There are also distinct gaps between analyses at different hierarchical levels, e.g. between the micro level (farm), the meso level (agricultural regions) and the macro level (market, countries or continents). Quantitative systems analysis approaches have been a common ground for integration of a number of disciplines, but one of the obstacles to the integration of research and to the cross-fertilisation of ideas from different disciplines is the variety of formalisms for system's representation, which is also reflected in the software tools implementing the research results. Agricultural systems research faces this problem, especially when systems are analysed at larger scales, where the interactions between social, environmental and economic systems cannot be ignored. As a result, different research groups develop and implement their research using incompatible software tools. Models and data are often hard-coded into the software and they are rarely re-usable. End users are often not clearly identified, resulting in the development of tools which cannot be used outside the environments for which they were developed.

The core deliverable of the Integrated Project SEAMLESS will be an Integrated Framework (SEAMLESS-IF) that enables simulation and analysis of effects of agricultural and rural developments, policies and innovations. SEAMLESS-IF will integrate quantitative, qualitative and participatory tools, and will include a software architecture and implementation (SEAMFRAME) for the technical integration of quantitative tools. The computer system will include modules that allow the users to simulate bottom-up and top-down effects of the biophysical, social and economic processes in agriculture on rural development.

This report provides the theoretical and methodological basis required for flexible conceptualisation of systems and associated model and tool development within the project. The report consists of two parts. The first part reviews general considerations of a systems approach in understanding complex systems and for performing integrated assessment studies. The second part of the report describes the different levels of conceptualisation that form the basis for integrated analysis and assessment of agricultural systems in SEAMLESS-IF. It proposes an assessment procedure and describes the main components of this procedure and their interrelationships.

2 Analysis and assessment of sustainability and sustainable development

Systems analysis has become an important science that deals with the analysis and understanding of complex, large scale systems and the interactions within those systems. It is typically used to guide decisions on issues such as resource use and protection policies, national or corporate plans and programs, research and development in technology, regional and urban development, etc.. The development of the conceptual framework for integrated assessment of sustainability and sustainable development in SEAMLESS-IF is based on systems analysis.

2.1 Systems concept

Systems' thinking has evolved as a result of the increasing complexity of problems that could not be addressed with more traditional, e.g. analytical approaches. The theory assumes that no matter how complex or diverse the world (that we experience) is, it will always be possible to find different types of organization in it, and such organization can be described by principles, which are independent from the specific issue that is subject to investigation. Systems' thinking is applied in a wide range of fields from industrial enterprises and armaments to esoteric topics of pure science (von Bertalanffy, 1976). Underlying theory refers to the transdisciplinary study of the abstract organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence. It investigates both the principles common to all complex entities, and the (usually mathematical) models which can be used to describe them (Heylighen and Joslyn, 1992).

A system is defined as a group of independent but interrelated elements comprising a unified whole that is relatively autonomous, self-organising, viable, sustainable and performing (see Box 1). System theory with application to agricultural systems has been significantly progressed by the work of De Wit (Leffelaar, 1999).

Box 1: System description

The systems concept includes: boundary and therefore system-environment composed of other systems, input and output and components (Bossel, 1989; Heylighen and Joslyn, 1992), (Fig. 1). A living system also performs due to processes and relationships among components. In addition, hierarchy, goal-directedness and information are also considered as part of the systems concept (Heylighen and Joslyn, 1992).

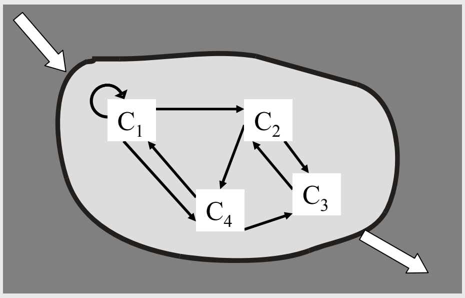

Figure 1. Schematic representation of a system within a given environment with boundary, components (C1…C4) and processes and relationships (bold arrows) among components. Interactions with the environment are through inputs and outputs (white arrows).

Problems related to sustainability and sustainable development are typically complex. The notion of complexity is vague and basically indicates that we have difficulties in understanding something. The simplest definition of a complex system refers to the whole that is more than the mere sum of its parts implying that understanding of the components of a system is not sufficient to understand its overall behavior. Other important features of complex systems are that relationships among components are non-linear and contain feedback loops; they are nested and open systems with boundaries that are difficult to determine. In fact, these systems are open where the relationships amongst the components of the system are usually more important than the components themselves (Cilliers, 2005). Complex systems are highly structured and are very sensitive to the initial conditions. Their behaviour is often chaotic as it is characterized by variations that are difficult to predict.

Analysis of complex systems requires integration of knowledge from different disciplines. These disciplines may be placed into three main groups representing the biophysical, social and economic aspects of the system (Figure 2). This is considered in the widely used triple P concept: Planet, Profit and People (Serageldin *et al.*, 1994) that emerged out of the Brundtland report on sustainable development (Brundtland, 1987). In the course of evaluating the progress in implementing the Agenda 21, the “Commission on Sustainable Development” of the United Nations defined sustainability as having not three but four dimensions (Spangenberg, 2002) adding institutions as the fourth dimension of sustainability.

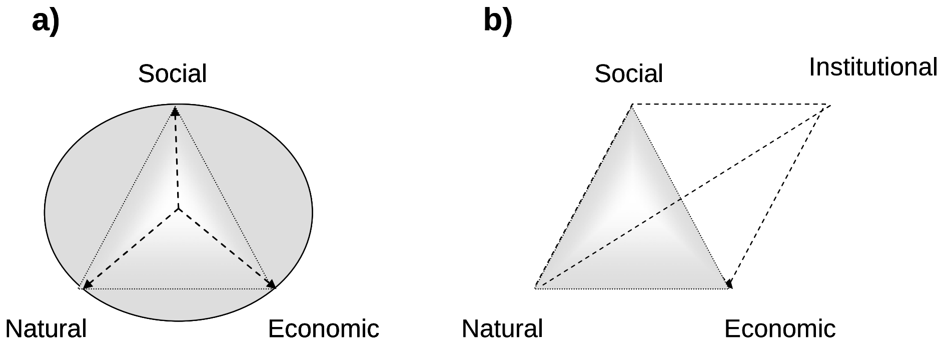

Figure 2. Schematic representation of a) three system aspects and b) consideration of institutions as the forth systems aspect.

Analysis of complex systems also faces the problem of integrating knowledge from different levels of the organisation. Hierarchy theory offers a concept for the investigation of systems that operate on several spatio-temporal scales (Weston and M.Ruth, 1997). It is a dialect of general systems theory and has emerged as part of a movement towards a general science of complexity. It focuses on levels of organization and issues of scale and the perspective of the observer of the system plays an important role. An example for hierarchical systems is the biological organisation as commonly used in ecology and environmental sciences with levels such as organism, population, community, landscape etc. (see Box 2).

Hierarchical systems have an organisational structure that refers to the shape of a pyramid, with each row of objects linked to objects directly beneath it (Figure 3). Thus, at a given level of resolution, a system is composed of interacting objects/components (i.e., lower-level entities or sub-systems) and is itself a component/object (or sub-system)) of a larger system (i.e., higher level entity). In fact, such nested systems are commonly called holarchic systems with holons representing the objects/components of the system. For the analysis of such systems it is not always required to account for the full complexity; concentration on objects/components that are of particular importance for the behaviour of the system may suffice (see also Figure 3b).

Scale issues are extremely important when describing processes. Proper scaling may decrease complexity (Parker *et al.*, 2002); only important relationships appear in the higher hierarchical levels and thus reduce complexity of components and simplify the analysis and interpretation of results.

Box 2: Hierarchical systems in agriculture

Different hierarchical systems can be identified in agriculture (Table 1). Hierarchical levels need to be identified for each specific study. A general hierarchy applicable to the largest possible range of issues does not exist.

Table 1. Hierarchies of different aspects of agricultural production

Biophysical	Economic	Social
		World
	World	Country Union (e.g. EU)
Biosphere	Country Union (e.g. EU)	Nation/Country
Ecosystem	Country	District/Region
Landscape	Agricultural Region	Village
Field	Farm	Household

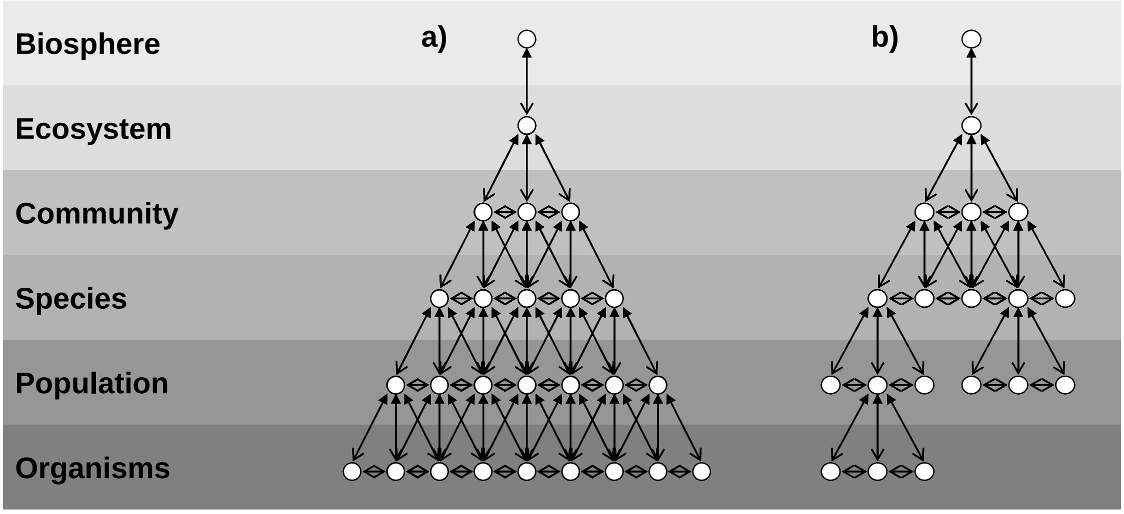

Figure 3. Schematic representation of a hierarchical system with a) fully or b) partially nested sub-system. Proper scaling (e.g. development of summary models) may reduce the nested detail (Fig. 3b).

2.2 Sustainability and sustainable development

Since the publication of the United Nations report on sustainable development (Brundtland, 1987), the concepts of sustainability and sustainable development have been adopted and adapted by most disciplines and sectors. Numerous definitions of sustainability and sustainable development have become available (Robinson, 2002), However in most definitions the need to maintain resilience in environmental and social systems by meeting a complex array of interacting environmental, social and economic conditions is central (Swart *et al.*, 2004).

The complexity of sustainability problems demand a holistic perspective that unifies across sectors, problems, methods, disciplines, spatial and temporal scales (Swart *et al.*, 2004). Systems theory provides a concept to address complex problems.

It has been argued that assessing sustainability is more a problem of prediction than of definition (Costanza and Patten, 1995). Following systems theory the basic idea of sustainability is straightforward; a sustainable system is simply a system that is able to survive or persist (Costanza and Patten, 1995). In extension, a system contributes to a sustainable development if its relationships to other co-existing systems including the higher level system in which it may be embedded do not hinder their existence. However, the understanding of complex systems and particularly of interrelationships between natural and socio-economic systems is fragmented and assessing the ability of integrated systems to survive or persist is not impossible. So, the prediction of sustainability and sustainable development remains difficult and only few conceptual approaches for estimating sustainability have been developed (see Box 3).

Systems performance in response to impact is commonly evaluated on the basis of attributes (orientors, goal functions) used to derive indicators. However, a vast list of attributes or orientors has been proposed to assess sustainability of environmental systems (Lopez-Ridaura *et al.*, In Press). The selection of appropriate attributes depends on the specific problem and the way the system is described.

Some approaches base indicator selection and sustainability assessment on understanding of the cycle of human induced environmental change. A widely used concept in this respect is the DPSIR (Driving force – Pressure – State – Impact – Response) framework. It has been adopted by a number of impact assessment models, e.g. IMAGE 2.0 (Alcamo *et al.*, 1994a; Alcamo *et al.*, 1994b), Mulino (Feás *et al.*, 2004). The concept appears suitable to understand and assess complex chains of cause and effect relationships among factors. However, emphasis is mainly on cause response relationships and understanding of the whole system and its behaviour is not central (in the meaning of essential) to the DPSIR concept.

Recent studies stress the importance of scenario analysis (including new participatory and problem-oriented approaches) as a powerful tool for integrating knowledge, scanning the future in an organized way and internalizing human choice into sustainability science (Swart *et al.*, 2004). Examination of the range of plausible future pathways of combined socio-economic and environmental systems under conditions of uncertainty, surprise, human choice and complexity is seen as key challenge.

Box 3: Approaches for sustainability assessment

Approaches may focus on the limits within which the specific system can change without irreversible damage (Klaassen and Opschoor, 1991) or on the capacity of the system to adapt to changes (Patten *et al.*, 2002), (Fig. 4).

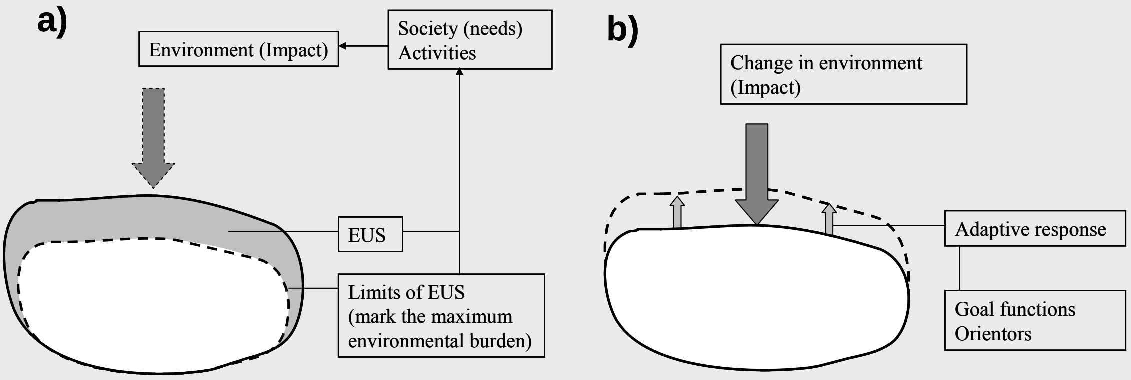

Figure 4. Conceptual representation to assess impact on the environment based on a) the environmental utilisation space, EUS and b) complex adaptive hierarchical systems, CAHS (see text for more explanation).

Another approach is based on finding compromises among natural and socio-economic objectives as expressed by stakeholders (van Ittersum *et al.*, 1998). This approach acknowledges the large uncertainties in our knowledge about the carrying capacity of systems and their adaptive capacity (WRR, 1995). Different attitudes of society and policy makers towards risks of dealing with these uncertainties exist. Scenarios ('action perspectives') may be defined for different confidence in the resilience of the environment (how much polution or global warming can an ecosystem stand) and society (how easily will a society adjust to alternative energy sources or will new technologies emerge and be accepted) (WRR, 1995; van Latesteijn, 1998). The contribution of science is to reveal the consequences of these different attitudes and to show trade-offs between environmental and socio-economic objectives (van Ittersum *et al.*, 1998).

Yet another approach is described by Bossel (2002) who proposes a set of main systems orientors as a basis for indicators selection for sustainability assessment in response to a set of environmental properties (Fig. 5).

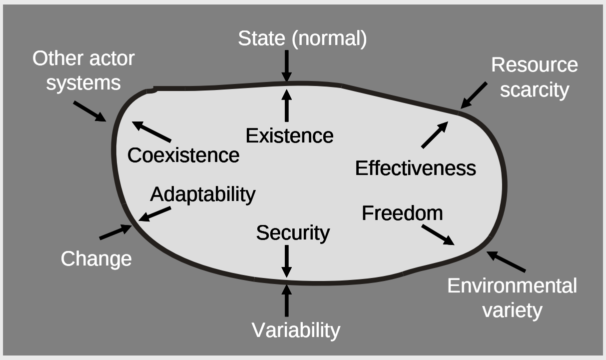

Figure 5. Basic system orientators which emerge in response to the properties of the system environment (Bossel, 2002).

2.3 Integrated assessment

2.3.1 Role of integrated assessment (IA) and modelling (IAM)

Integrated assessment and modelling has been suggested as a solution to the management of complex environmental systems. It is a way of systems thinking; a way to balance the different aspects (biophysical, institutional, social and economic) of the system (Harris, 2002). It is an analytical approach that seeks to gain insight from the analysis of interactions (Rosenberg and Edmonds, 2005). IA has been defined as "an interdisciplinary and participatory process combining, interpreting and communicating knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena" (Rothman and Robinson, 1997). Thus, in IA the process of understanding and management of environmental systems is seen as a joint activity between scientist and decision makers. In this respect, IAM is responsive to (groups of) stakeholders. In fact, IAM represents a problem-focused area of research, i.e. mainly project based and undertaken depending on stakeholder needs or demands (Parker *et al.*, 2002). Modelling is not seen anymore as a purely scientific activity that provides systems descriptions and prescriptions for decision makers but as a participatory approach with strong emphasis on communication.

However, there is also some criticism related to IAM; it largely relies on existing knowledge and models and mainly combines old areas of science and research to gain new insight in a more holistic way. Also, the identification of systems and systems characteristics such as boundaries and components is largely subjective and goal-driven. In that way the selection of stakeholders including scientists will determine the formulation of the problem and the characterisation of the system(s) including the ways to analyse it. Also, despite the impressive variety of sub-systems incorporated in the most advanced IAMs, political, cultural and institutional processes are hardly considered (Shackley and Wynne, 1995).

Integration is a key goal for IAM but difficult to be truly achieved in practice. However, the process of integration may provide results that could be more important than the actual outcome of the assessment. At least five types of integration have been identified (Parker *et al.*, 2002). Integration of issues is central and is reinforced by the integration of stakeholders, disciplines, scales and models. A number of IA frameworks have been developed (see Box 4).

Box 4: Examples of Integrated Assessment (IA) frameworks

IA frameworks and tools for application to environmental problems (Rosenberg and Edmonds, 2005):
MERGE (Manne *et al.*, 1995), IMAGE 1.0 (Rotmans *et al.*, 1990), IMAGE 2.0 (Alcamo *et al.*, 1994a; Alcamo *et al.*, 1994b), RICE and DICE (Nordhaus and Boyer, 1994; Nordhaus, 1996; van Latesteijn, 1998), ICAM (Dowlatabadi and Morgan, 1993; Dowlatabadi and Ball, 1994; Morgan and Dowlatabadi, 1996), MIT Integrated Global System Model (Prinn *et al.*, 1999), AIM (Morita *et al.*, 1994), MARIA (Mori and Takahashi, 1999; Mori, 2000), ASF (Sankovski *et al.*, 2000), TARGETS (Rotmans and de Vries, 1997)

IA frameworks and tools for application to agricultural problems:
IA has been most advanced with respect to research on climate change impact assessment. Prominent examples are known for the US, e.g. the MINK study (Rosenberg, 1993) and a more advanced recent effort, (see special issue Climatic Change, 2005, Vol. 69, No.1) and for Europe (Downing *et al.*, 1999).

Other examples are the integrated agro-ecological economic modelling system based on CRAM (Canadian Regional Agricultural Model) and EPIC (Erosion Productivity Impact Calculator), (Bouzaher, et al, (1995).

Yet another example is the modelling framework ADIEM (Kulshreshtha and Klein, 1989) of agricultural drought impacts at the level of soil, farm business and region ADIEM.

Lauwers *et al.* (1998) present an integrated modelling framework to account for the effect of manure policies on regional disposal and from there to pig farm level.

Borresch *et al.* (2005) presents an approach to quantify economic, hydrologic and biodiversity indicators as measures of landscapes' multifunctionality for various plots at the regional level.

2.3.2 Concept and procedure

Different conceptual approaches and methods have been developed for integrated assessment. (Rothman and Robinson, 1997) propose a conceptual framework within which individual IA studies, and the practice of IA as a whole, can be placed and evaluated. Eight elements have been included in this framework (Table 2). The first six address the integrative nature of IAs and the development of interdisciplinarity and the latter two address the policy usefulness of IAs and the self-awareness of their role and capabilities

Table 2. Categories in a conceptual framework for integrated assessment (Rothman and Robinson, 1997)

Location in the cycle (vertical integration)
Scope: Sectoral, regional, and issue (horizontal integration)
Consideration of feedbacks and dynamics
Human adaptation to environmental change and policies to address this change
Recognizing multiple baselines
Quantitative/qualitative dimensions
Policy driven analysis
Involvement of stakeholders

A fairly static and linear view of integrating the different stages of the cycle of human-induced environmental change is suggested (also referred to as vertical integration), but it allows comparison of the IAs with respect to the degree of vertical integration (Figure 6), (Rothman and Robinson, 1997).

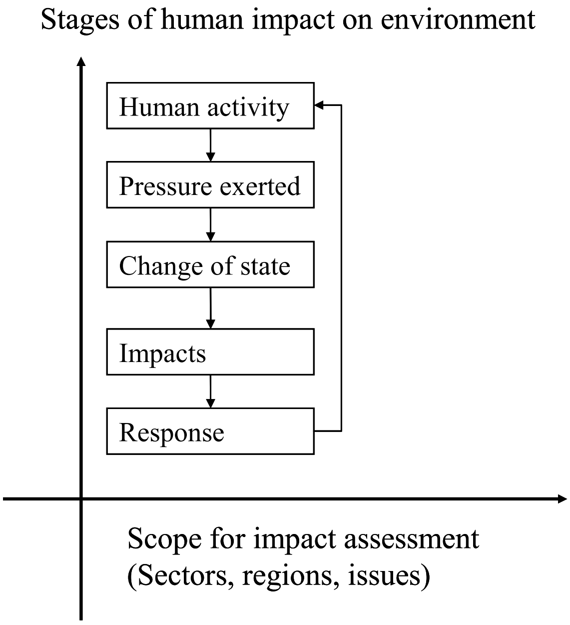

Figure 6. Conceptual representation of vertical and horizontal integration for integrated assessment, see also Table 2 and (Rothman and Robinson, 1997)

Gough *et al*, (1998) distinguishe between actors and disciplines (Fig. 5). Actors are stakeholders (e.g. citizens, policy makers, etc.) and can be identified at different levels of the organisation. Vertical and horizontal integration refer to the integration of different actors and disciplines, respectively (Fig.7).

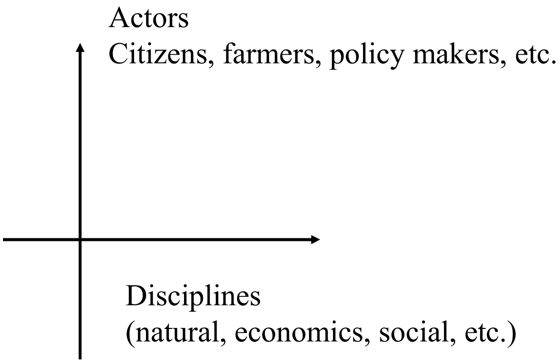

Figure 7: Vertical and horizontal integration for IA as proposed by (Gough *et al.*, 1998).

The horizontal linkage of models from different disciplines is most commonly used in IAM. Such 'knowledge-nets' have been critically discussed in comparison to 'knowledge pyramids' representing a more hierarchical relationship between different knowledge domains (Shackley and Wynne, 1995). The philosophy behind the 'knowledge pyramid' is that integrated knowledge should be built up from the more certain, objective and quantitative knowledge of the physical, chemical and biological process. At a later stage this should be supplemented by knowledge of socioeconomic impacts and responses (Shackley and Wynne, 1995). In comparison, in 'knowledge-nets' all components are treated equally important.

Special attention should be given to the procedures used in IA. The sequence of steps used for IA usually depends on the specific approach and application. A participatory and integrated planning procedure for decision making in water resource systems is proposed by Castelletti and Sessa (2004) and includes the following steps.

(1) Expression of stakeholder preferences and goals
(2) Identification of the indicators used to assess movement towards goals
(3) Development of a conceptual framework, encompassing objective functions, decision problems and conceptual model formulation
(4) Analysis, including formulation of detailed models and management policies
(5) Assessment of system performance under a range of scenarios

User/stakeholder questions and specification of indicators, models, data and scenarios are important components of IA and are also of relevance for SEAMLESS-IF.

2.4 Development of indicators

2.4.1 Principles of indicator development

Indicators are an aggregation of information that indicates the change or define the status of something. Indicators are most frequently based on quantifiable data but may also be based on qualitative information depending on the purpose of the indicator (Gallopin, 1997). There are a number of perspectives how to structure indicators (see Box 5).

Box 5: Ways of classifying indicators:

i) Classification by stocks and flows (Meadows, 1998). Stocks are indicators of the state of a system and its response time. Flows indicators are indicating change.
ii) Classification by disciplines and experts involved. We (following CSD, 2001) distinguish economic, environmental, social and institutional indicators. Within the disciplines indicators can be further structured e.g. environmental by media, toxicity, source of the problem etc.
iii) Classification by policy instruments; Linking problems and instruments: some problems are accessible with regulatory policy the others require economic incentives or moral persuasion.
iv) Classification by regions and scales: from field to globe, South, North, East (New MS), West (Old MS).
v) Classification by users: experts, non-experts, users at local level, et national level, EU level, the levels in the public administration hierarchy, political science clustering

Indicators are used to communicate complex information between experts form different scientific fields, decision-makers and different groups of stakeholders (Bell and Morse, 2003; European Commission, 2001; European Environmental Agency, 2004; Giampietro, 1997; Malkina-Pykh, 2002).

Even though well known and frequently used there are several problems and difficulties related to the development of indicators; some of these problems are more technical others are related to the use of indicators in the policy process. Several principles for creating legitimate indicators have been proposed (e.g. Hardi and Zdan, 1997; Meadows, 1998), (see Box 6).

Box 6: Principles for indicator development
(e.g. Hardi and Zdan, 1997; Meadows, 1998)

Policy relevant

This means that an indicator system should reflect the structure of the existing debates give continuity and not try to introduce a “better” structure, it should also be taken into consideration that the information need will change over time which means that the indicator system has to be flexible. An indicator system should also establish a vision of sustainable development in terms of clear goals and practical definition that are meaningful for the decision-makers as well as the actors involved in the debate.

Practical

Any assessment needs to merge a sense of the overall system with a practical focus on current priority issues. Indicators should be:

- appropriate in scale (not over or under aggregated)
- hierarchical i.e. that users can explore down to details
- aggregation methods must be transparent
- value elements (e.g. weighting coefficients) must be clearly separated from objective elements

Based on standardised measurements

Indicators must be based on standardised measurements to enable comparison (wherever possible). One often mentioned example is the Gross National Product GDP.

Related to a reference level

Indicator values should be put in the context of reference levels i.e. targets, critical ranges, thresholds, or directions of trends to assess the progress toward sustainability and achievements of policy goals.

2.4.2 Hierarchy theory - a system for indicator aggregation

The amount of data, statistics, indicators and indices surveyed by statistical offices, field research or model is overwhelming (see Box 7). Aggregation is necessary to avoid information overload in the decision-making system. However, aggregation is also associated with loss of information which emphasises the need for proper aggregation. Hierarchy theory described in section 1.1 offers a theoretical basis for indicator aggregation of systems that operate on several spatio-temporal scales. It focuses upon levels of organization and issues of scale.

Two opposite approaches of how to develop indicators within hierarchical structures have been presented (Ronchi *et al.*, 2002). Either shortened sets of headline indicators are selected (these vary by sector or theme), or an aggregation procedure is adopted that allows the creation of unique integrated indices. Aggregation commonly starts with raw data. The application of algorithms, models and statistics produces regional and national indicators in relation to all four aspects of SD. At the top, the key headline indicators are selected for each domain. Following a bottom up integration process, a suitable combination of the key indicators may give a global index for each domain.

There is a trade-off between the need to simplify and condense information and the desire to make decision processes more transparent. Meadows (1998) argues that aggregation should be done in a transparent way which enable users to follow the “information iceberg” and identify which data have been used and which data have not been used to make the aggregate indicator. For example, it should be possible for anyone to find out not only *that* the gross agricultural output (GAO) went up, but *what* went up (crop production or livestock production, etc.).

Non-experts have only a limited capacity to aggregate large numbers of indicators. However, since climbing towards the top of the information iceberg poses considerable difficulties a standardised approach (weighting) is crucial to support the political debate.

Box 7: The information Iceberg

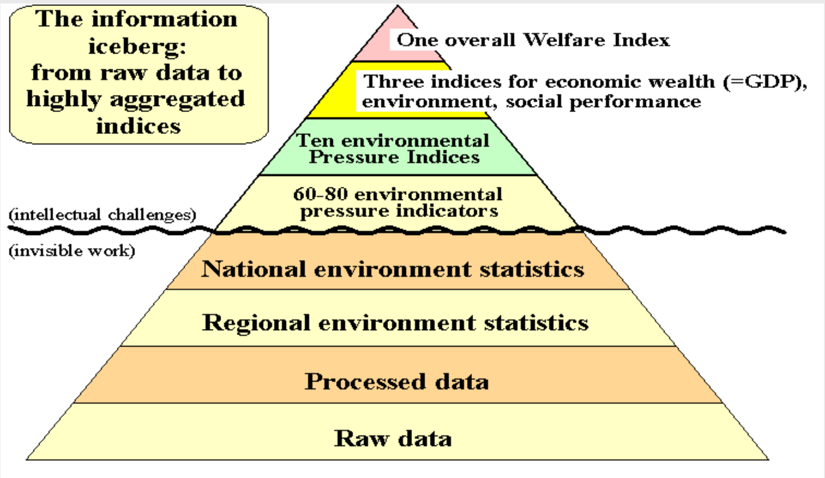

Figure 8. The information iceberg.

Data: Data are figures that need further processing (e.g. aggregation to national level, adjustment for season, climate, economic cycles etc.), before they can be called statistics.
Statistics: Statistics are official figures, which have been produced with standardized definitions.
Indicators: Indicators are "executive summaries" addressed to non-experts who want to get a quick impression of basic trends without the need for further interpretation.
Index: Is used for indicators related to a baseline year ("Index 1990=100") or for **aggregation of indicators with similar impacts**. An index is an amalgam of more than one indicator. The main purpose of such aggregations is to communicate detailed information to an audience that requires condensed, "simplified" information.

2.4.3 Creating frameworks for linking indicators

Until recently most indicators focused on one issue at the time. However, the work on Sustainable Development Indicators (SDI) aims to develop a framework that brings together the economic, social, environmental and institutional aspects of society, emphasising the links between them. Such framework defines the aim and purpose of the indicators as well as to whom and why they are to be communicated, i.e. which is the perspective that is taken. As argued the usefulness of indicators can be increased by putting them in an appropriate framework which makes intuitive sense, captures the relative importance of various indicators, and illustrates their mutual relationship (Meadows, 1997). A framework should hence help to increase the understanding of the present situation and the rate and direction of change. Several frameworks for indicator development have been developed (see Box 8).

Box 8: Frameworks of indicator development (see appendix I for explanation)

- target levels and endpoint frameworks
- driving force- pressure-state-impact- response framework
- basic satisfaction framework
- short and long-term framework
- four capital framework

2.5 Contribution of modelling

2.5.1 Approaches and types of models

Models are a simplified representation of the real world with a specific goal. The aims of the model and the available knowledge about processes and relationships define the structure and detail of the model.

Modelling represents a powerful method to integrate theory and empirical knowledge. It can be seen as the linking point where science finds consideration in integrated assessment studies. In fact, modelling is often seen as the central part of IA (Bland, 1999; Jakeman and Letcher, 2003).

Models can aid exploration of the behaviour of a system under various conditions from which to determine the dominant factors. They can also assist with data collection and interpretation and parameter estimation. Moreover, models can support assessment and control of potential impacts on systems.

Models are used to describe, explain and predict and can be divided into theoretical, parametrical and simulation models. Models can also be classified into types (see Box 9).

Box 9: Important types of models in biophysics and economics

Biophysics:

- empirical, phenomenological and mechanistic models,
- dynamic and static models,
- deterministic and stochastic models,
- reductionistic and holistic models, etc. (Jorgensen and Bendoricchio, 2001).

Economics:

- econometric and optimisation models
- household (consumption function), firm-level (production, profit functions) and market models (supply, demand functions)
- normative and positive models.

Complex interactions between agro-ecological and socio-economic phenomena are analysed by means of bio-economic modelling. Kruseman (2000) defines bio-economic as “a quantitative methodology that adequately accounts for biophysical and socio-economic processes and combines knowledge in such a way that results are relevant to both social and biophysical sciences”. The development of bio-economic modelling approaches is rooted in both bio-physical and social sciences (see also Box 10). Kruseman (2000) presents an extensive review of bio-economic modelling approaches pointing to descriptive explanatory, explorative and predictive bio-economic models assessing their capacity in terms of number of issues addressed and the aggregation level (plot, farm household, village or watershed, regional and higher).

Models have a dual role with respect to indicators:

- On one hand, an "a priori" selection of indicators will orientate the modelling work, guiding modellers about what information is expected from their models.
- On the other hand, the cause-effect relationships used to select indicators are usually of a very complex nature. Models are powerful tools to (partly) consider this complexity for indicator calculation.

Box 10: More information on bio-economic modelling

Bio-economic models began with a normative approach. The objective was getting rules in order to ameliorate the exploitation of natural resources. These were usually dynamic models in which the transition equations where built out of biological models (population dynamics, concerning usually fish or forestry populations). Often dynamic programming was used (Wilen, 1985; Kennedy, 1986). Usually these type of models were poorly adapted to analyse impacts of policy changes. Firstly, because they where strictly normative, and to analyse policy impacts we need models able to begin reproducing real behaviour of the agents in the system. Secondly, the methods of resolution imply working with a very small number of variables. There are very few examples in which more complex systems are treated using this approach (Standiford and Howitt, 1992; Yates and Rehman, 1998).

Difficulties in integrating formulized knowledge from different disciplines are largely due to differences among models in the conceptual and methodological approaches used including their spatial and temporal resolution. Model linkage will require identification of a spatio-temporal unit that is commonly shared by all models considered in an analysis.

Following Malkina-Pykh (2002), integrated assessment models are suitable tools for systematically structuring the interlinkages between indicators. The main advantages of linking a set of indicators to a modelling framework are that it: (i) shows how the various indicators are interlinked (linkages within the cause-effect chain of an issue (vertical integration) and between different issues (horizontal integration)); (ii) yields insights into the relevance and dynamic behavior of indicators (behavioral patterns of social, economic and environmental systems); (iii) enables projections for sustainable development (long-term trends for social, economic and environmental indicators); (iv) identifies critical system variables and offers a guide for the selection and aggregation of indicators; (v) may result in a more comprehensive set of indicators, where model variables which appear to be of pivotal importance for trend projections are not yet part of the existing set of indicators; (vi) may serve as a guide for the further development of the integrated modelling framework. Such coherent and integrative information can only be generated by an interconnected framework of indicators.

2.5.2 Data needs

The diversity of models used in integrated modelling, the inclusion of both quantitative and qualitative indicators and the hierarchical system approach result in a very complex demand for data. The data have to provide information on the biophysical, social, economic and institutional aspects of a system. Furthermore, the data need to be organised to support modelling and assessments at different spatial scales.

To provide the necessary data the challenge is to bring together existing datasets that have been generated for very different purposes and with very different methods. For example data on agriculture have been generated with the purpose of monitoring the agricultural sector mainly from an economic point of view. On the other hand data have been gathered on environmental issues mainly to provide information on the state of the environment and linked to assessment of environmental issues. Other critical issues with respect to the use of data in modelling and assessment studies have been identified (see Box 11).

Box 11: Critical issues for the use of data in modelling and assessment studies

1. It is important that the characteristics and limitations of the different databases are transparent. It is therefore crucial that coherent and detailed metadata are elaborated.
2. Decisions on how to organise the dataset dates back as far as to the late 1960ies (as for some EU-level agriculture data, (Andersen *et al.*, In press). These datasets often lack crucial information that is needed to assess current (EU agricultural) policies as aims and objectives of the policies have changed over time. This means that information on some issues has to be provided from other sources than the consistent (EU-level) databases and that this information will be imperfect taken into consideration the variety of agricultural systems. To remedy this it is necessary to develop methods, such as typologies, to link data from different data sources.
3. Databases are organised at different spatial levels ranging from administrative regions to very detail grid systems with a variety of purpose specific regions in between. This means that the different databases cannot easily be linked and that methods need to be developed to integrate the data spatially.

2.6 Scenarios

According to Schoute *et al.* (1995), a scenario is a description of the current situation, of a possible or desirable future state as well as of the series of events that could lead from the current to the future state. Stressing consistency and objectives of scenarios, Pearman (1988) states that a scenario is a hypothetical sequence of logical and plausible (but not necessarily probable) events, constructed in order to focus attention on causal processes and decision points. Scenarios do not aim at predicting but rather at exploring the future (Gault *et al.*, 1987; van Ittersum *et al.*, 1998) through possible future states. In a policy decision context, scenarios allow policy makers to anticipate and assess risks involved in different options and to identify alternative courses of action (Malafant and Fordham, 1997).

Scenarios can be of a descriptive or normative nature (Nijkamp and Blaas, 1994) and they can be assembled from a forecasting or a backcasting point of view (see Box 12). They can be based on a common opinion or the knowledge of experts and they can be constructed as menu-driven or policy packages (Shiftan *et al.*, 2003). Swart *et al.* (2004) review the history and current frontiers of scenario analysis (see Box 13). In the context of sustainability science, integrated scenarios may be thought of as coherent and plausible stories about the possible pathways of combined human and environmental systems. They generally include a definition of problem boundaries, a characterization of current conditions and processes driving change, an identification of critical uncertainties and assumptions on how they are resolved, and images of the future.

Scenarios are designed in all imaginable areas of science that use modelling. (Lyons, In Press) locates some commonly used management tools and processes within Humphreys' framework (Humphreys, 1986) to resolve initially unstructured problems in business environment. In this framework, models are used (a) to structure the problem (conceptual models, diagrams) and (b) to interpret its complex structure (econometric models, game theory, simulations, expert systems, sensitivity analysis). Scenario development is used to set the boundaries and identify choice of frames. Scenarios in economic analysis are typically descriptive and reflect assumptions -employing scenarios with different assumptions- and uncertainties about exogenous variables of the system, i.e., about the economic framework conditions relevant to the system. For example, quantitative and qualitative models analysing the development of a single sector of the economy are influenced by developments in the rest of the national and the international economy. Plausible assumptions on economic growth, currency exchange rates, population, etc. are exogenous to sectoral models and therefore constitute typical elements of the scenario. In a policy context, the formulations of different policy options are central elements of scenarios. Combined with assumptions on economic framework conditions, possibly varied according to the uncertainty involved, the scenario analysis allows assessing the consequences and risks associated with policy choices. A limitation of policy oriented scenario analysis is that it might not lead to an optimal policy but to a predefined set of policy options considered in the scenarios. However, a flexible mechanism of analysis with rather quick response times and accessible output allows for the definition of scenarios in an interactive process with prime users of the scenario analysis. This user-dialogue might help the decision maker to implicitly learn about and express preferences by assessing the complex outcomes of the scenario analysis (Heckelei, 1998).

In a global context, an important function of scenario development is the exploration of potential future shocks, or discontinuity, as it is referred in the literature (Van Notten *et al.*, 2005). By examining 22 studies from a broad set of approximately 70 scenario studies, Van Notten *et al.* (2005) concluded that not just the concept of discontinuity is poorly defined but also that half of the examined studies omit discontinuity. Since scenario development is a means to prepare for the future, discontinuity should be explored to avoid unexpected sudden impacts on society.

Box 12: Important types of scenarios

Descriptive and normative scenarios

Descriptive scenarios describe possible developments and start from what we know about current conditions and trends. Normative scenarios are constructed to lead to a future that is afforded a specific subjective value by the scenario authors (Swart *et al.*, 2004).

The choice between descriptive or normative scenarios is dependent on the objectives of the scenario development exercise. Normative scenarios represent organized attempts at evaluating the feasibility and consequences of trying to achieve certain desired outcomes or avoid the risks of undesirable ones. Descriptive scenario analysis, on the other hand, tries to articulate different plausible future societal developments and explore their consequences. The latter is typically used in the context of evaluating different policy options.

Quantitative (modelling) and qualitative (narrative) scenarios

Quantitative analysis often relies on formal models, using mathematical algorithms and relationships to represent key features of human and environmental systems. Quantitative modelling is often used for predictive analysis, which is appropriate for simulating well-understood systems over sufficiently short times. Quantitative scenario analysis often needs to be complemented by qualitative scenario exploration, which can capture non-quantifiable issues such as values, cultural shifts and institutional features. The scenario narrative gives voice to these important qualitative factors, providing a broader perspective than the one offered by mathematical modelling alone. However, qualitative knowledge may imply uncertainties regarding assumptions used by quantitative models and consequently lead back to the exploration of different plausible quantitative scenarios reflecting the range of these uncertainties.

Forecasting and backcasting scenarios

Forecasting scenarios explore alternative developments, starting from the current situation with or without expected/desired policy efforts. Backcasting scenarios reason from a desired future situation and offer a number of different strategies to reach this situation (Glossary of the European Environmental Agency).

Box 13: Evolution of scenario thinking

The broad use of the term "scenario" for characterizing the systematic framing of uncertain possibilities can be traced to post-World War II strategic studies, exploring possible consequences of nuclear proliferation. In the private sector, Shell has played a leading role since the 1970s developing scenarios to highlight world development possibilities that are relevant to the company's future, and to prepare company managers for responding to an uncertain future (Schwartz, 1991; Shell, 2002). Mathematical simulations were used to forecast the behavior of the economy, its pressures on the environment, and resource constraints. Another stream of scenario work has focused on envisioning desirable futures, particularly in the energy field, in order to stimulate discussions on how to get there. This backcasting approach has been applied in the context of sustainable futures, at both regional and global scales (e.g. Robinson *et al.*, 1996; Raskin *et al.*, 1998). In the context of the sustainability, global scenarios focusing on issues such as climate change, water scarcity, public health, and land use were developed (Rotmans and Vries, 1997). The IPCC (Intergovernmental Panel on Climate Change) series of greenhouse gas emissions scenarios studies became successively more sophisticated (IPCC, 2000; Nakicenovic and Swart, 2000). In the IPCC Special Report on Emission Scenarios (SRES) different "non-intervention" and "intervention" scenarios were defined and assessed by implementing respectively specific climate change targets and policy measures with the primary goal of reducing greenhouse gas emissions. SRES scenarios have been widely used to assess climate change impacts on agriculture (e.g. Ewert *et al.*, 2005; Rounsevell *et al.*, 2005). This defined taxonomy (intervention/non-intervention) is however somehow ambiguous, since the information available might be insufficient to determine whether or not scenarios include any additional climate policy initiatives.

2.7 Technical solutions for integrated assessment

One of the obstacles to the integration of research and to the cross-fertilisation of ideas from different disciplines is the variety of formalisms, which is also reflected in the software tools implementing the research results. Systems research faces this problem, especially when systems are analysed at larger scales, where the interactions between social, environmental and economic systems cannot be ignored. As a result, different research groups develop and implement their research using incompatible software tools. Models and data are often hard-coded into the software and they are *rarely re-usable*. End users are often not clearly identified, resulting in the development of tools which cannot be used outside the environments for which they were developed.

Researchers have been aware of this problem since the very moment they started to develop models, but the effort of building *open and reusable software* has always been greater than the final reward. Thanks to innovations in software engineering, and to increase the rewards, and to the advances in the integration and in the inter-disciplinary approach to research some progress has been made.

The first attempts have been pioneered in the field of management science, where Dolk and Kottemann (1993), influenced by Geoffrion's structured modelling (1987), introduced the concept of *model integration*, identifying major issues such as model, data and solver independence, and proposing innovative solutions. Software tools such as GAMS and AMPL have been greatly influenced by their work. Similar concepts and ideas were used to develop model integration frameworks for water resources management. Some of the first efforts (see a review in Rizzoli *et al.* (1998)) evolved into the most successful current examples of modelling frameworks, such as MMS (Leavesley *et al.*, 1996), ModCom (Hillyer *et al.*, 2003), TIME (Rahman *et al.*, 2003) and OpenMI (Gijsbers *et al.*, 2003). Thanks to advances in software engineering (Szyperski *et al.*, 2002) and to the cited developments in the implementation and use of modelling frameworks, integrated projects can target the ambitious goal of providing a new approach to the integration of science for systems analysis and management.

A desirable architecture of a software system to support integrated assessment requires a *generic modelling framework*, which in turn provides a number of *software components* which can be assembled to deliver the *specific software applications* needed to address specific issues in an integrated modelling framework. The generic modelling framework provides a set of software components which provide services such as structured access to the various data sources (data base mediators), a library of models (model base), a modelling environment, and a set of algorithms to manipulated and transform data and models, typically simulators, optimisers, calibration routines, data analysis and presentation tools. Examples of such frameworks are OpenMI (Gregersen and Blind, 2004), TIME (Rahman *et al.*, 2004), MMS (Leavesley *et al.*, 1996).

Software developers can use the framework to build dedicated applications, which implement *workflows* and provide a graphical user interface. A workflow is a sequence of tasks performed by calling a succession of software components. The most evident distinction between a software application and a software component is the lack of a user interface in the component, which in turn has a programming interface (i.e. a component can be seen as a software library).

Yet, a generic modelling framework and specialised software applications are not enough to solve the key issues of integrated assessment, that are related to the integration and re-use of knowledge at different scales. Thus, the software architecture must be based on the very same principles we have exposed for hierarchical systems in the previous sections. Models, data, workflows and applications must all possess the *closure* property. A model can be composed of submodels, but its interface will hide the model complexity to the uninterested user, which can be also another model. The same holds for data, which can be aggregated at various levels, and for workflows, which can also be made of simpler workflows.

From the implementation viewpoint, the key to provide such a scalable and modular architecture is to adopt component-based programming (Szyperski *et al.*, 2002). This programming paradigm is at the basis of most recent Application Development Frameworks such as Java 2 Enterprise Edition (J2EEE) and Microsoft Visual Studio .NET. Components are deployed independently and they are completely described by their interfaces. Modern features of programming languages such as reflection and introspection (ins cit.) enable a component to adapt to another component simply according to the specified interface. This allows, for instance, to implement a simulation tool which reads the interface of a model component and is able to provide the required data in the correct format to perform a scenario analysis over a given range of conditions.

The down side of using components is that they strongly enforce the concept of information hiding, which is not particularly welcome when it comes to understand and explore the structure of an integrated model. This is why a component-base software architecture must imperatively be complemented by a semantically-rich approach to data and model descriptions. We advocate the use of the declarative modelling paradigm (Muetzelfeldt, 2004), as opposed to the traditional imperative style of model coding. The declarative approach is complemented by the use of ontologies (Ceccaroni *et al.*, 2004) to specify the meaning of the various model elements: inputs, states, outputs, parameters and equations.

Declarative modelling and ontologies are complementary and orthogonal to component-based software engineering and they provide the levels to design and build a software framework for integrated assessment.

2.8 The role of case studies

The analysis of complex hierarchical systems and their contribution to sustainable development requires a good balance between various techniques and methods. What defines a “good balance” is determined by the issue studied. Case studies allow putting the evaluation of the system in the context of a specific issue. Detailed information is made available to assess the validity, scope and limitations of the system being evaluated using qualitative research methods (Verschuren and Doorewaard, 1999). A case study validating modelling concepts is characterised by a small number of research units, labour-intensive data generation and a strategically selected sample.

Evaluation under conditions representative for a realistic application is an essential step in the process of development of each tool of analysis (indicators, databases, models, software architecture, qualitative tools, and participatory methods), and of the integrated framework as a whole. There are two reasons for this evaluation:

- it is a component of the methodology to build up the models and associated tools, in a progress loop (conceptualise-test-improve)
- it is a demonstration of the performances (scientific and technical) and of the applicability, robustness and reliability of the tools in a user context.

When systems are simple enough and studied for a long time, the models and assessment tools can be tested by the help of expert knowledge in the context of theoretical case studies. With the complex environmental systems considered in SEAMLESS we can make the assumption that no expert alone is able to understand its complexity and to predict its behaviour. The integrated modelling framework and its associated tools must therefore be evaluated based upon typical examples of real systems with enough data and expert knowledge on each of their components. To demonstrate the performance and applicability of a policy assessment tool, the case studies should be defined only by a set of external constraints to be applied to the environmental system and a set of indicators to assess the behaviour of this system and its components as they are perceived by users and stakeholders. The case studies should be carefully selected to cover a large range of external constraints (both biophysical and socio-economic) and to involve all the subsystems that are important in the system’s behaviour. The assessment of the system’s behaviour and response to impact is performed by analysing how indicators change when the environment moves from a reference scenario (describing a probable future) to a policy scenario.

2.9 Communication of knowledge and participatory methods

Recent studies implementing integrated frameworks pay a great deal of attention to communication of information and participatory methods of involving stakeholders to a specific policy issues. Communication is the critical factor for the success or failure of integrated studies (Parker *et al.*, 2002). The traditional mode of knowledge production is by many considered to be insufficient for meeting the challenges related to sustainable development and its implications for the future development of our society. The way in which science have been organized and pursued since the World War II is increasingly challenged by scientists as well as a wider community of stakeholders. Concepts such as “mode 2 knowledge” and “co-evolution of knowledge” (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001), “Postacademic Science” (Ziman, 2002) and “post-normal science” (Funtowicz and Ravetz, 1992; Gallopin *et al.*, 2001) is trying to define new ways of pursuing science for solving urgent problems in the society. Another important concept put forward by Nowotny *et al.* (2001) is the *Agora*, being a discussion place and a melting pot of all kinds of discussions about knowledge. The *Agora* can be seen as a common name for networks and institutions (such as universities, ministries, NGOs, scientific and other media, etc.) with influence on the production of knowledge. The *Agora* provides the basis for what Gibbons and collaborators (Gibbons *et al.*, 1994) call “mode 2” science. The difference between mode 1 and mode 2 science is found at several levels, such as:

- Mode 1 science is focused (in terms of methods as well as theory) on a set of problems defined as important by the academic discipline, while mode 2 science focus on problems defined as important by a broader community (the society). Mode 2 science therefore lacks homogeneity of methods and theory.
- Mode 1 knowledge is produced in isolation within universities while mode 2 knowledge is the result of active participation of several and different kinds of stakeholders in an integrated process.
- The quality of mode 1 science is assessed through peer review, a process in which quality and control of what is deemed important mutually reinforce one another, while in mode 2 science quality and relevance are assessed in relation to questions such as: will the solution be found? will it be cost effective? will it be socially acceptable?

Research findings in mode 1 science are mainly communicated through scientific channels to the scientific community, while in mode 2 science the results are communicated in various ways to the ones who have participated in the process as well as a wider community of concerned stakeholders.

3 A concept for analysis and assessment of agricultural system(s) in SEAMLESS-IF

3.1 General overview

This section describes the conceptual approach, which will form the basis for SEAMLESS-IF. The developed concept evolved out of the theoretical information presented in section 2 (Analysis and assessment of sustainability and sustainable development) and from discussions in several workshops with partners of work package 1. The development of this concept is a dynamic process. It will continuously be improved as more knowledge and expertise about integrated analysis and assessment of agricultural systems becomes available.

For the performance of integrated assessment to support (policy) planning and decision-making, three basic levels of conceptualisation need to be distinguished:

1. *delineation of a theoretical framework for analysis and assessment*
   This refers to the way we think and want to conceptualise a problem. It describes and frames the problem including the aims and types of analysis; are we interested in sustainability and/or multifunctionality or vulnerability etc.. It includes identification of the principle method to be used, e.g. analysis of impacts, risks analysis, life cycle analysis, Ecological Footprint, material flow analysis etc.. The defined framework will determine indicator selection and model formulation.
2. *specification of a procedure for analysis and assessment*
   This refers to the workflow that is used to perform analysis and assessment including the use of results to support policy decision-making. It should clarify the individual steps of the procedure, their sequence and interactions used for a specific study.
3. *model formulation*
   This refers to the modelling concept(s) and clarifies which and how things will eventually be modelled.

Ideally, SEAMLESS-IF will support activities at all three levels. However, not all activities will require the SEAMLESS-IF environment but may be facilitated by the IF. For instance, theoretical thinking about how to conceptualise sustainability and impact assessment is an activity that will be done outside the IF. However, the IF may provide information about available concepts (knowledge base) and guide the thinking process by providing some basic components and methodologies for integrated impact assessment.

These basic components of the integrated assessment process are summarised in Figure 9. Important relationships among these components are indicated and frame a basic procedure used for integrated analysis and assessment within SEAMLESS-IF. The sequence of steps characterising the basic workflow of assessment together with the products produced by SEAMLESS-IF for each component are reported in Table 3.

There are more relationships and feedbacks among these components than indicated in Figure 9 that may be of importance for specific studies. The following sections will provide a more detailed description of the individual components and the information flow to and from other components. For some components, a first attempt is made to explain the methodology used to develop information required by other components. A detailed description of the specific methodologies used within SEAMLESS-IF will be provided by the reports PD1.3.1 to PD1.3.7 which will be summarised in the report PD 1.3.8.

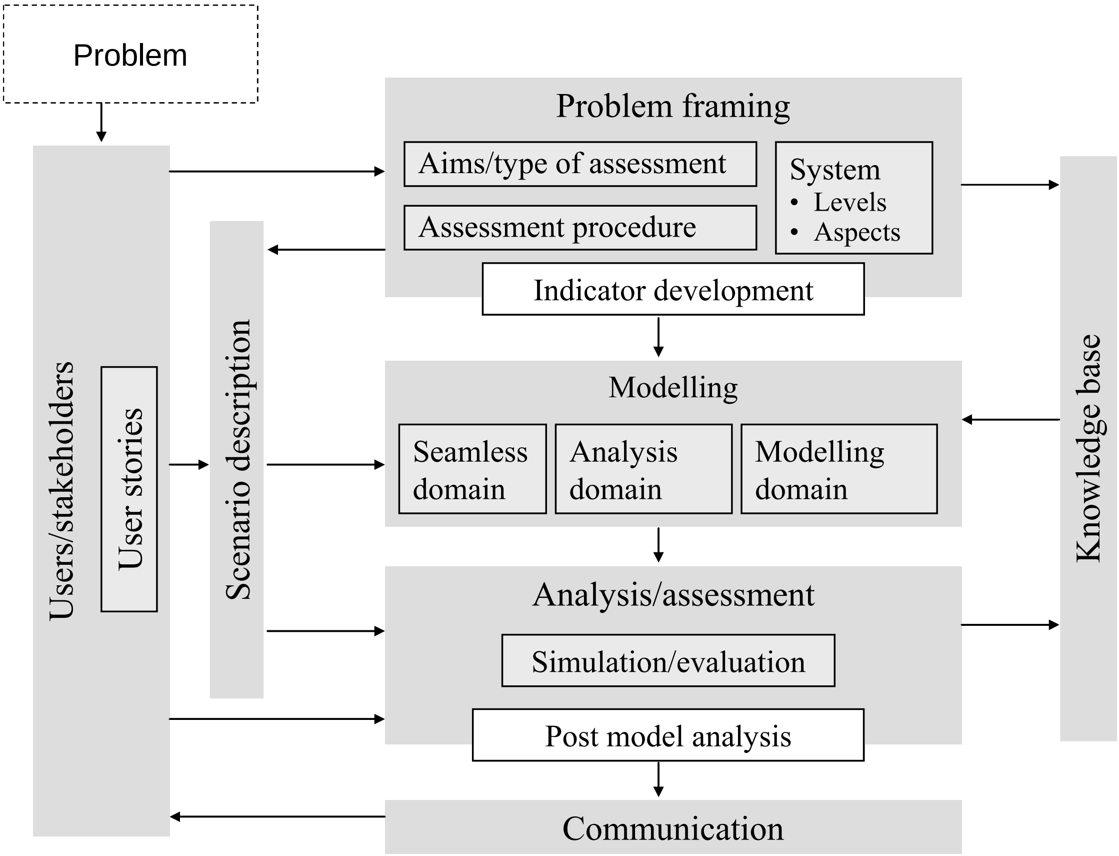

Figure 9. Main components for integrated assessment of agricultural systems within SEAMLESS-IF. The indicated relationships characterise the basic procedure used for impact assessment (see also Table 3). Feedbacks and flexibility in designing the assessment process are not specifically indicated but are explained in the text.

Table 3. Components, procedure (steps of workflow) and products required for integrated assessment of agricultural systems within SEAMLESS-IF.

Step	Component	Product
0	Problem	
1	Formulation of user stories	Set of user questions
2	Framing the problem	Specified concept of impact assessment and system description
3	Scenario development	Scenario framework, specification of scenarios
4	Indicator development	Indicator framework, selection of indicators
5	Modelling	Concepts for model formulation (application, business, computation domain)
6	Analysis and assessment (including post model analysis)	Concept for model analysis, evaluation and synthesis
8	Development of knowledge base	Knowledge base
9	Communication	Concept for communication and participatory approaches

3.2 Users stories

An initial step for analysis and assessment of integrated systems in agriculture is to tell the full story (narrative) of the problem to be analysed. Ideally, a set of questions is formulated that captures the full range of issues related to the problem addressed. However, in reality, the set of questions formulated will be biased towards the specific expertise and interests of the stakeholders considered. There are potentially many different kinds of stakeholders (e.g. farmers, consumers, food and transport industry) at many different levels (e.g. farm to EU and international). Key stakeholders representing different parts of the specific problem should primarily be considered in the formulation of the full story.

An example for a specific problem with a set of user questions is given in Box 14. An advanced set of narratives can be obtained from Appendix II.

Box 14: Example with selected user questions for a specific problem.

WTO negotiations and sugar prices
What will happen if all EU subsidies and trade limitations on sugar are lifted in the November 2005 WTO Hong Kong Round? There will be consequences in EU regions producing sugar both directly in terms of farmers' responses and indirectly in terms of industrial and transport changes. There may also be effects outside the EU in terms of increased income opportunities in developing countries. This might be interpreted as if the EU agriculture contributes to sustainable development outside EU.

1. What will happen to the price of sugar?
2. How much sugar will be produced in EU?
3. Where in the EU will sugar be produced and where will production cease?
4. How much sugar will be imported?
5. How will agriculture in the developing countries be affected by the change in sugar policy in EU?
6. How many sugar factories in EU can stay in business?
7. How many workers will be unemployed due to the closing of sugar factories?
8. What other crops will be grown instead of sugar beet?
9. What will be the impact on leakage of N and P from agricultural land?

3.3 Framing the problem and describing the system

In the next step these user stories require structuring to clarify the range of issues that should be considered and how they should be considered. This includes (Fig. 10):

(1) Clarification about the aims/objectives and type/concept of assessment
(2) Specification of assessment procedure
(3) Description and structuring the system

Theoretical understanding of systems analysis and integrated assessment will assist the structuring of user questions. As a result, the concept and procedure for impact assessment for the particular study is defined, which will be the basis for scenario development, indicator selection and model formulation.

A possible way of addressing sustainability (and structuring the problem including user questions) is the DPSIR approach (see appendix I). A possible procedure to support the assessment and planning process is the PIP (Participatory Integrated Planning) procedure (Castelletti and Sessa, 2004).

Structuring the system includes clarification about the spatial and temporal scales including hierarchical linkages, the aspects of the system considered and important sub-systems and a description of their characteristics (i.e. system boundaries, system components, important relationships, input and outputs etc.), (Fig. 11).

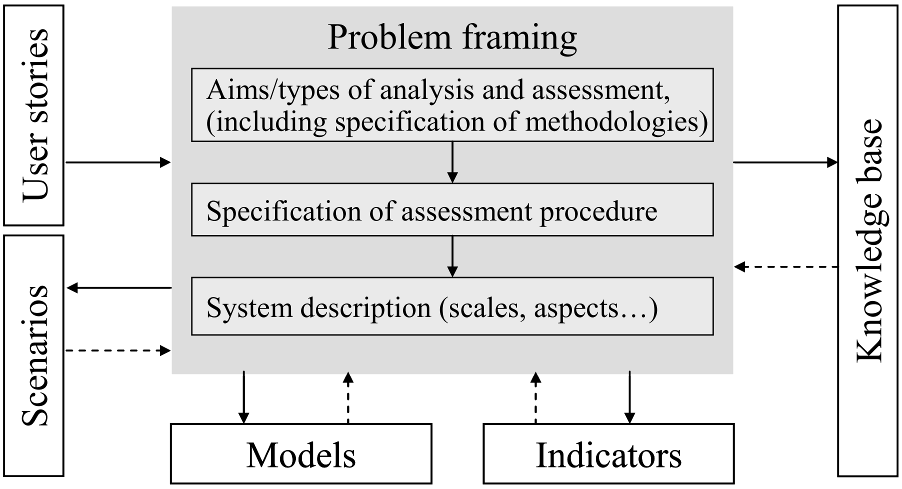

Figure 10. Activities within the problem framing component and relationships to other components.

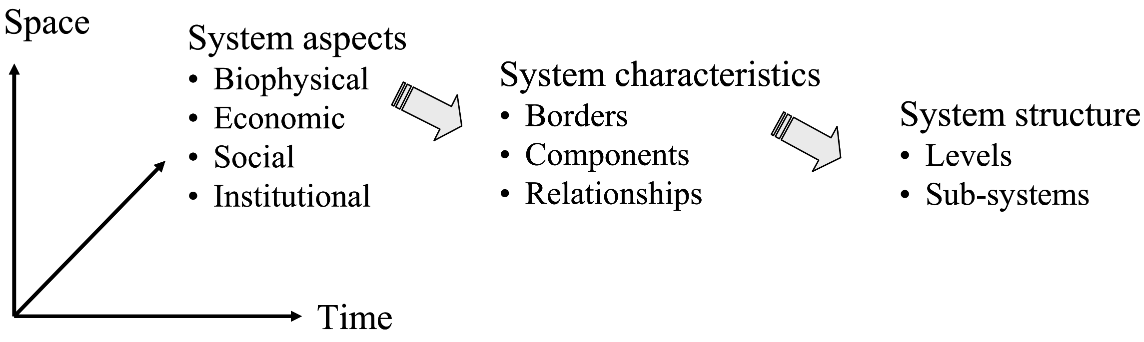

Figure 11. Proposed characteristics for system description.

The agricultural system(s) that is the primary subject of investigation within the SEAMLESS Integrated Project can only be characterised in general terms (see Box 15). A more detailed description of the system will depend on the specific problem to be solved. In SEAMLESS-IP main emphasis is on farming systems and rural development within the EU. The physical boundaries of the system are the borders of the EU. Any regions outside the EU are considered as environment that may affect (or may be affected by) agriculture within the EU. However, many other characteristics of the system cannot be defined explicitly and require clarification about the goal of the analysis. More specific descriptions of agricultural systems are provided for the regions considered in the test cases (see report PD 6.1.1 compiled by WP6).

Box 15: General characteristics of the spatial and temporal dimensions and the aspects of the agricultural system(s) subject to investigation in SEAMLESS-IP.

System characteristic	Dimension		Aspect		
	Spatial	Temporal	Biophysical	Economic	Social
Borders	EU-25 land area	Historic (<50 years) Future (≤10 years)	Directly managed natural resources	Economic units directly depending on agricultural production	Directly involved (rural) communities
Environment	Land area outside EU-25 and non agricultural activities inside EU	Historic (<50 years) Future (≤10 years)	Atmosphere and climate Open water, other (non-agricultural) land uses	Economic units that affect agricultural economy	Communities not related to agricultural production
Components	Fields, farms, landscapes, watersheds, NUTS regions, countries, EU	Days to years	Soil, plants, animals, landscapes, biodiversity, pollution	Farm, administrative region, country, EU	Farm household, rural community, country, EU
Structure	Variable spatial resolution	Variable time steps	Large number and high diversity of components and connections, asymmetric, strong interactions, hierarchy and holarchic organization		
Relationships			static, dynamic, linear, non-linear, causal, autonomous, evolutionary		
Input/output	Variable (goal dependent)				
Hierarchy			Multiple variable hierarchies		
Goal	Variable (often multiple) goals related to sustainability, sustainable development and multifunctionality				
Information	Open, living system with high requirements for (variable) information processing				

3.4 Scenario development

Once the user stories and the domain have been formulated and described, alternative scenarios representing alternative pathways of future development will be specified. Relationships with other components of the assessment process are summarised in Fig. 12.

In order to provide a consistent set of assumptions on determinants exogenous to SEAMLESS the scenario definition should comprise three elements (Fig. 12):

(1) Setting/Objectives;
(2) Identification of exogenous variables;
(3) Scenario database.

First of all, the scenario *setting* and the *objectives* of analysis have to be identified. This implies a verbal description of the specific research issue considered (the "shock" to be assessed, e.g. a policy change), a contextual overview on the political and scientific relevance, and a characterization of the desired type of information by SEAMLESS-IF with respect to geographical and time scale, selected tools and indicators. Once the system is described, this part of the scenario will emerge from the procedures developed for user involvement and in interaction with tool/indicator identification.

Given a certain set of selected tools and indicators, the complete collection of relevant *exogenous variables and system conditions* need to be identified. This might include demand shifts for agricultural products in the EU and worldwide, exchange rates, rates of technical progress, premiums paid for various production activities, global and regional climate indicators, etc.

Finally, a *database* with concrete numerical values for all the required exogenous variables and specification of qualitative attributes and indicators needs to be established serving as reference and input data for the application of the tools. Possibilities for documentation of sources (projection by some organization, expert opinion, etc) and definitions are part of this database. Potentially different sources for the same variables shall be included to provide information of uncertainty on scenario variables and enable sensitivity analyses as part of the scenario description. The database will be continuously updated with any new application.

SEAMLESS-IF is a tool for impact assessment. The question to be analysed is – generally speaking – the impact of a shock to the system, e.g. a policy change or some technological innovation. The definition of the shock to be assessed is done by differentiating a *baseline* (or reference) scenario from an *impact* (or policy and contrasting) scenario (Fig. 13). Both scenarios differ only with respect to the specific shock in the focus of analysis to allow for a with/without comparison. The impact of the shock is assessed by comparing indicators assessed via tools and models under the baseline scenario ("without") with indicators under the impact scenario ("with").

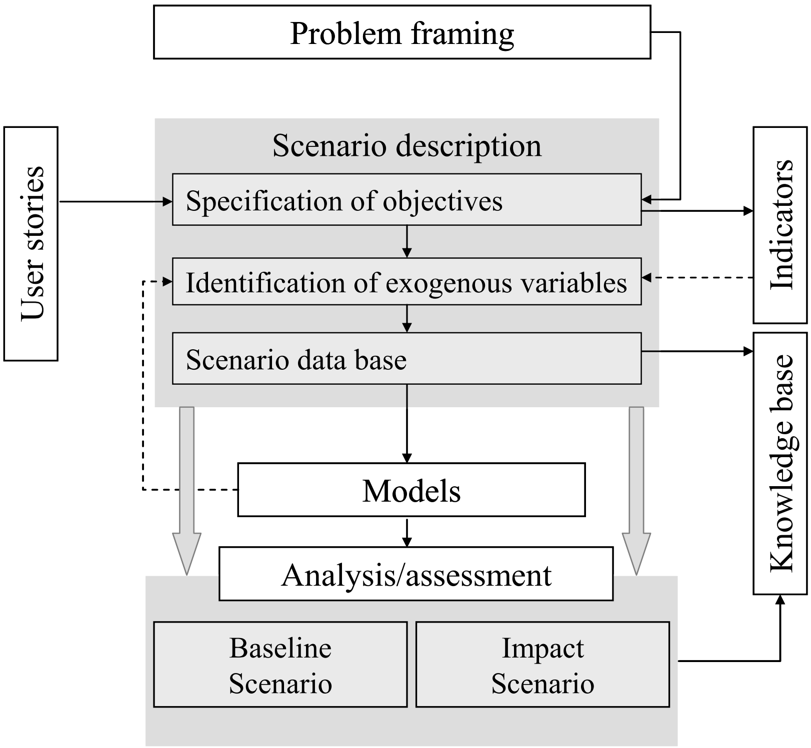

Figure 12. Activities within the scenario component and relationships to other components. It should be noted that impact scenario refers to both, policy and contrasting scenario.

3.5 Indicator selection

Indicator selection will depend on how we structure (and want to address) the problem including the scenarios that will be identified for a specific assessment study. However, in some cases indicators may already be available and support the domain description and scenario development (Fig. 13). Indicator selection will largely determine the modelling process. Models will be selected and linked according to their ability to estimate these indicators. Again, in some cases available modelling concepts (including scientific data and statistics) may be used to define indicators.

Different elements of indicator development can be identified (Fig. 13):

(1) Identification of objectives/concept of sustainability assessment;
(2) Identification of indicator framework and aggregation methods;
(3) Selection of indicators (including specification of thresholds and targets);
(4) Aggregation of indicators

Indicator development for SEAMLESS-IF has to meet several objectives (Box 16), which will eventually determine the methodological concept(s) used for indicator selection including aggregation (see report PD 2.2.1 and Box 17) Several concepts for structuring indicators are available (see reports PD 2.2.1 and PD 2.2.2) but require detailed investigation to understand their relevance for SEAMLESS-IF.

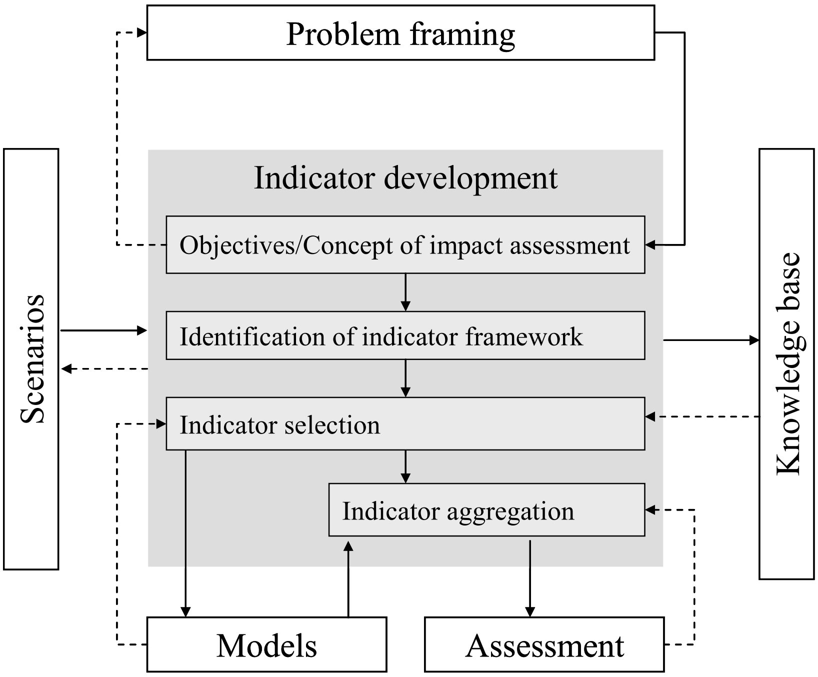

Figure 13. Activities within the indicator component and relationships to other components.

Box 16: Challenging objectives for indicator development within SEAMLESS

SEAMLESS is interested in indicators, which should support the political debate on sustainable agriculture through ex-ante assessment of agricultural, environmental and rural development policies from the point of view of sustainable development. To make SEAMLESS sufficiently universal we will need a number of indicators and aggregation methodologies which will fit all potential issues within the domain of SEAMLESS.

The ambition within SEAMLESS is to create a standardised weighting methodology as well as define a framework within which indicators will be created. The aggregation methodology (weighting) will be critical for the success of SEAMLESS. The ambition within SEAMLESS must therefore be to create a standardised weighting methodology. This aggregation methodology (weighting) will be critical for the success of SEAMLESS.

Until now it has been difficult to assess European agricultural and rural policy objectives at EU, national and regional levels (Brouwer and Lowe, 2000; Baldock *et al.*, 2001; Dwyer *et al.*, 2002). The reason is partly because of the lack of consistent and accepted indicators of sustainability across multiple scales (CEC, 2000). The large diversity of farming systems in Europe requires that indicators and aggregation procedures must reflect regional, economic, environmental and social differences on one hand but still provide condensed information on the other hand.

Box 17: A methodological approach of indicator aggregation

Development of indicators may be structured along the information iceberg i.e. in the first stage, based on results of other scientists, statistical figures and our models' outputs we will build "thematic" indicators (environmental, social, economic and institutional indicators); in the second stage we will look for interrelationships between indicators, particularly the concept of multi-functionality will be adopted. Finally, thematic and multiple indicators will be aggregated to a set of policy relevant indicators and indices.

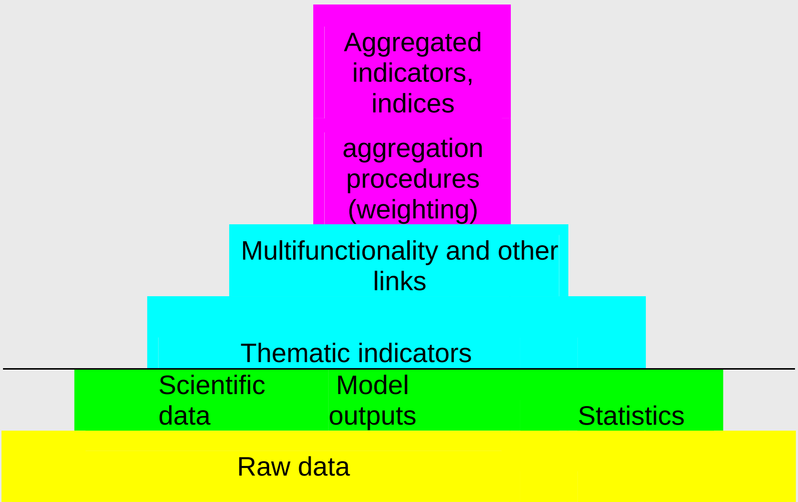

Figure 14. Concept for indicator aggregation.

3.6 Modelling

Modelling is a central (but not the only) activity for integrated assessment. SEAMLESS-IF should facilitate modelling in a multi-disciplinary environment aiming at grasping the whole complexity of the agri-environmental domain. Participants come from many different disciplines, each having their own jargon and world-views. To be able to build a common framework a common conceptualization is required to:

- share common understanding of the structure of information among ourselves;
- enable re-use of knowledge (see section 2.8 Knowledge base for definition)
- operationalise the domain and assumptions about it;
- build and fill a knowledge base (see section 2.8 Knowledge base for definition).

It is generally accepted that this conceptual model must have a common ground in all scientific domains. Furthermore, the application of SEAMLESS-IF will deal with different worlds, the agri-environmental world, the analysis world and the technical world. It is, therefore, important that the conceptual model covers and integrates these levels. Thus, the conceptual model can play an important role in the development of the SEAMLESS integrated framework.

Levels of integration:

We distinguish between three levels of domains to build the conceptual model for (see Box 18 for further description):

1. The Seamless (Se) domain (or agri-environmental domain)
2. The Analysis (A) domain (or workflow domain)
3. The Modelling (M) domain

Box 18: Explanation of SeAM models

Seamless domain

Seamless domain is the subject of our study, our 'business'. We have defined this so far as the agri-environment domain including ecological, social, economical and institutional aspects.

The conceptual model of the Seamless domain will be based on the concepts Actor-Action-Environment-Condition (Fig. 15). In short the relations between these concepts can be defined as follows: Actors take (meaningful) Actions that operate on 'Things' in an Environment. And the 'Things' in an Environment impose Conditions onto Actors. Actors will take appropriate Actions to deal with these Conditions, and so on.

Analysis Domain

The computation domain refers to the 'world' of making use of models in modelling exercises, the 'analysis world'. In this domain we describe what we aim to achieve with the data and model results. We can determine, based on the different user roles, several tasks with SEAMLESS-IF:

- Analyze (current policy)
- Simulate (business as usual, a new policy etc.)
- Communicate (what happens if …)
- Evaluate and assess impact (scenario's)
- Visualize (results, outcomes etc.)

The most important concepts in the analysis domain are scenario's and indicators. A scenario is a specific input dataset with the objective to assess the impact of a change (e.g. a policy measure or a technological innovation). A indicators is a tool to simplify, measure, and evaluate (e.g. sustainable) development and to communicate this information. Other concepts in the computational domain can relate to model development tasks such as sensitivity analysis, validation, robustness testing, parameter-fitting etc.

Modelling domain

The Modelling (sub)domain reflects the way how we technically want to create / compose / assemble models and how we want to package and distribute them in software applications and components.

The modelling domain is supported by Seamframe, the software architecture of SEAMLESS-IF (Fig. 16), which provides the modelers with a set of software components which can be used, combined, re-used and re-combined in a variety of ways, in order to organise and structure data and create and develop models.

The domain editor provides support to structure and organize data by means of Ontologies which connect concepts in a meaningful way and lend themselves to powerful and intuitive forms of interactive graphical representation.

The model builder provides a sets of libraries and classes for model composition and reuse. New models can be made available and stored in the model base. Models are stored in an XML-based model-representation language. The model builder is capable of taking a declaratively-represented model as input and producing (for example): some type of description of the model (e.g. HTML); an executable version of the model; a transformation of the model (e.g. to simplify it, thus addressing the scaling problem).

Executable versions of models are objects, which can be further processed by Processing Tools, which are software components. Among processing tools we list algorithms for simulation, optimisation, data analysis, etc.

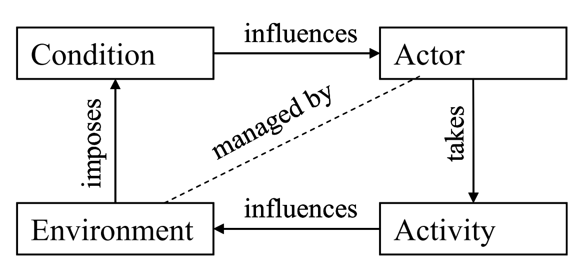

Figure 15. Conceptual model of the Seamless domain; Actor-Action-Environment-Condition concept

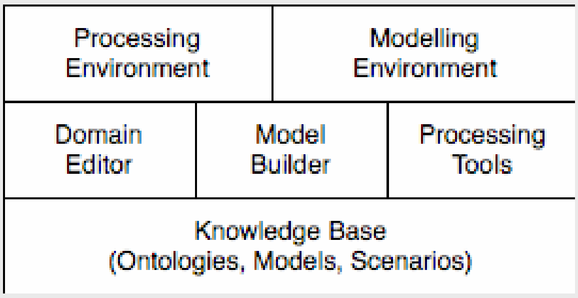

Figure 16. The software architecture of Seamframe

The Seamless domain is the real 'world', our 'business'. We have defined this so far as the agri-environment domain including ecological, social, economical and institutional aspects. The analysis subdomain is the world in which we analyse the real 'world' by making use of applications packaging models. The modelling domain reflects the 'technical world'. It deals with the way how we want to create/compose/assemble models .

Each domain is in fact a separate dimension, orthogonally situated to the others. It is important that we have a shared understanding about all three 'worlds' and that we integrate these 'worlds' consistently. Only this way it is possible to deliver a comprehensive product of use to all user roles.

Gluing together:
The SeAM domains are different (orthogonal) views of the modelling system. It is important to recognize how the models relate. A first attempt of relationships among these domains is summarized in Appendix III.

Models used:
Studying agricultural systems implies that a range of different sub-systems have to be considered. Relationships between these systems are complex and integration of models that operate at different temporal and spatial scales and represent different disciplines and thinking concepts (see Box 19) poses considerable difficulties. Particularly difficult is the linkage of models representing sub-systems at the lower levels of the organisation (e.g. farm, agricultural region, basin or catchments level) applied to relatively small spatial scales with models from the higher levels of organisation applied to large spatial scales (i.e. market level).

Scaling and linking models:
The proposed conceptual model from the business domain, i.e. the Actor-Action-Environment-Condition concept, provides a suitable approach to allow scaling of information across levels of the organization (see Box 20). It enables both vertical (i.e. across actors) and horizontal integration (i.e. across disciplines and spatio-temporal scales), (see Fig. 6 in section 1.3). The concept is consistent with ideas of linking models from different disciplines representing different subject domains including spatial and temporal scales (see Box 20).

Box 19: Types of models used in SEAMLESS and selected characteristics

Bio physical models:

- Spatial scale: plot of homogeneous soil with a defined weather structure, including variability on time
- Time scale: long term, for taking into account cumulative effects on natural resources and environment. Recursive structure: past influences future but future do not influence past as in inter-temporal optimisation models
- Biophysical processes are modelled as well as human intervention in an interactive way
- In terms of information flows, APES receives data from nature (i.e. climate, soils, etc.) and from human activities (weather, soil, techniques, rotations, etc) and provides information on a very wide range of outputs (yields, pollution, change in the soil state, etc.)

Economic models (Bio-economic farm models FSSIM):

- Spatial scale: the farm, as a decision unit composed of several plots of soil allowing for heterogeneity
- Time structure: can be static or dynamic. In the case of dynamic it can be recursive (independent optimisation for each period, past influence future) or inter-temporal optimisation (optimisation of a flow for a defined time horizon) or dynamic-recursive (a mixture of the two previous)
- Positive approach: models should be able to reproduce real situations and to react to exogenous and endogenous changes (policies, effects of agricultural practices on productivity of natural resources)
- Information flows:
    - Part of information comes from APES: Yields, emissions, impacts on soil erosion, etc
    - Other information comes from statistical sources, surveys, users' requirements: prices, labour use, costs, size of farms (DATA BASES), policy framework
    - At the level of farm bio-economic modelling, prices and policies are clearly exogenous, but it is planned to use an iterative loop with the market model in order to define the prices in a specific simulation exercise. On the other side, also linkages with bio-physical models may need feed-backs.

Market models:

Agricultural Sector Model (CAPRI), Global Model (GTAP)

- Spatial scale: European Union for CAPRI, the World for GTAP. There is also a world market module in CAPRI.
- Time structure: comparative-static.
- Positive approach: models should be able to reproduce real situations and to react to exogenous and endogenous changes (policies, effects of agricultural practices on productivity of natural resources)
- Information flows:
    - Part of information comes from FSSIM, for estimating the supply side of CAPRI
    - Other information comes from statistical sources, surveys, users' requirements: prices, labour use, costs, size of farms (DATA BASES), policy framework

(At the level of market modelling, prices are endogenous.)

Landscape models:

- Spatial scale: Regional
- Time structure: static
- Information flows: in principle, these models will be "passive", they should be able to reflect the impact on landscape produced by the results obtained from the simulations done using the other models

Box 20: Proposed concept for scaling and related model linkage

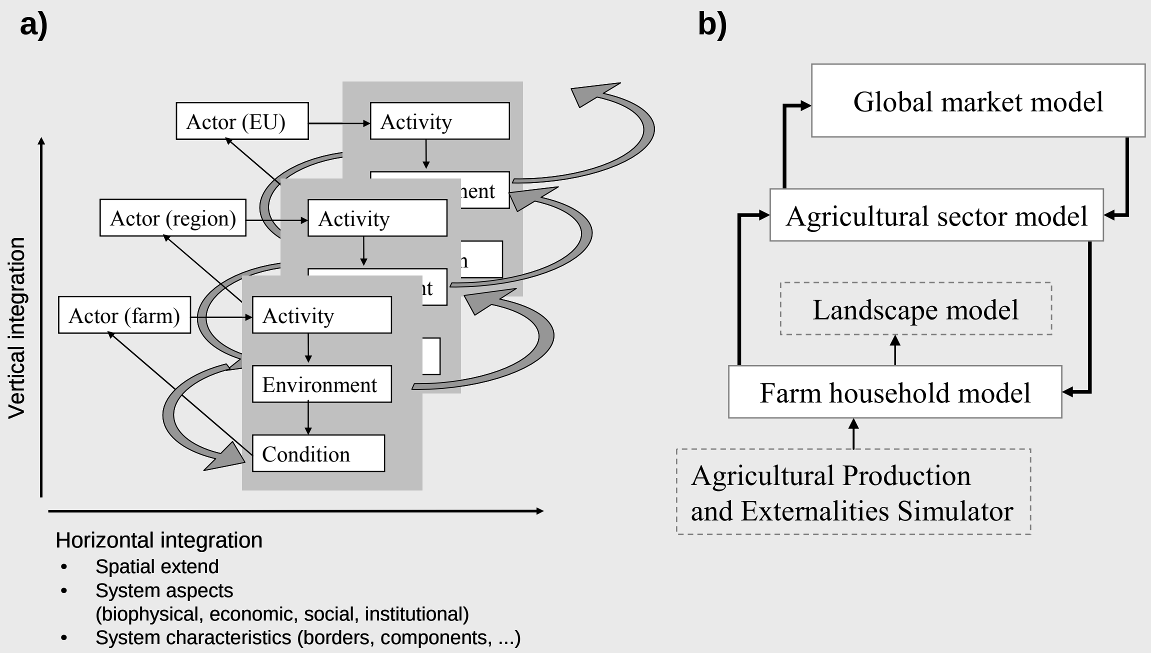

Figure 17. (a) Vertical and horizontal scaling based on the Actor-Action-Environment-Condition concept and (b) related model linkages

3.7 Analysis and assessment

Once the indicators for impact assessment and the models to quantify these indicators have been identified analysis of impacts can be performed. Models will be run for different scenarios (policy *vs.* baseline) using data provided by the knowledge base (Fig. 18). Indicators that cannot be assessed with quantitative models will be evaluated post to model simulations. Accordingly, the analysis and assessment process can be separated into the (quantitative) model and post-model analysis. A more precise description of the different steps includes:

(1) Model simulations for alternative scenarios including visualisation of results;
(2) Analysis of qualitative indicators;
(3) Advanced analysis including sensitivity and uncertainty analysis
(4) Synthesis and evaluation of indicators (this will include aggregation, weighing and rating etc. of indicators, multi-criteria analysis etc. strongly dependent on how the problem has been framed)
(5) Visualisation of results, comparing indicators values for baseline and policy scenarios.

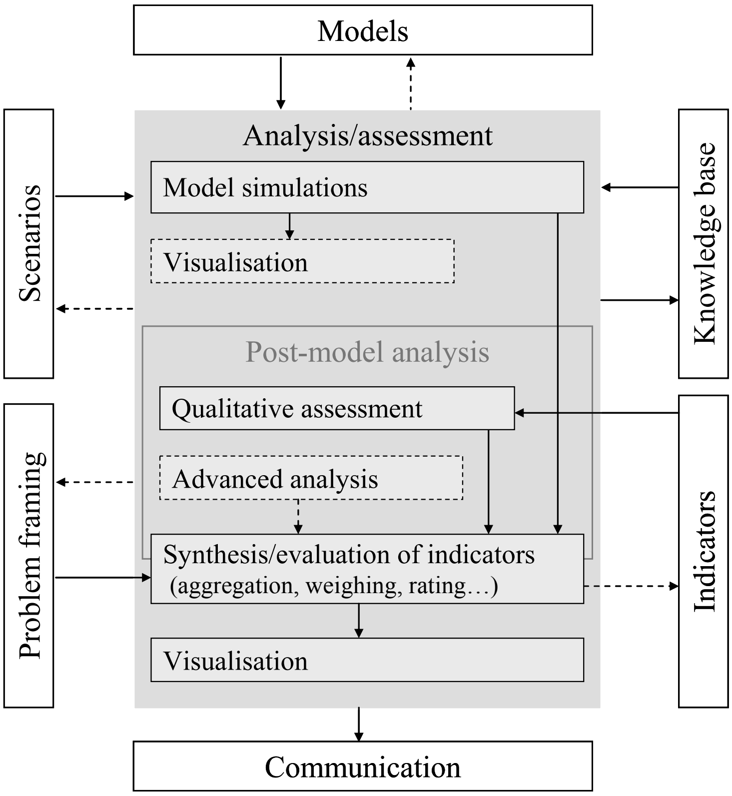

Figure 18. Activities within the analysis and assessment component and relationships to other components.

3.8 Knowledge base

Knowledge is a vague term. In a wider sense it means awareness and understanding of facts, truths or information gained in the form of experience or learning. In SEAMLESS-IF knowledge refers to data as well as to information related to indicators, scenarios, models, assessment results etc.. Data and information will be assembled, stored and maintained in the knowledge base.

The knowledge base has two main tasks:

(1) To provide information to the different components of the assessment process
(2) To save information that becomes available from the different components (including models, indicators, scenarios, results, etc.)

In particular, the knowledge base will save and provide information to the components:

- Domain structure
- Scenarios
- Indicators
- Model formulation (including model chain etc.)
- Analysis and assessment of results

The diversity of models used in integrated modelling, the inclusion of both quantitative and qualitative indicators and the hierarchical system approach result in a very complex demand for data. The data have to cover information on systems elements, its social, economic and ecological environment. Furthermore, the data need to be organised to support modelling and assessments at different spatial scales. This poses considerable difficulties in organising and populating a data base (see Box 21).

Box 21: Specific problems envisaged for different types of data

For the environmental issues much consistent information is available for EU-25. However, the need for detailed information for farm and field level modelling still needs to be specified. Furthermore, the data might not always be available at the appropriate scale. The biggest challenge in relation to the environmental data is therefore to adapt the data to a common spatial format suitable for the modelling in SEAMLESS. Another big task will be to check the consistency of the databases available across EU-25. The differences in the quality of the data across the Member States need to be identified, as the information in the databases might have been collected and adapted in different ways in the different Member States. Also in relation to the quality of the data the temporal consistency within and between databases need to be identified and evaluated.

For the data on farming systems consistent data are available across EU-15 from the Farm Accountancy Data Network (FADN) and from the Farm Structural Survey (FSS). For this type of data the challenge will therefore be to get access to comparable data from the new Member states, to facilitate the marked level modelling in Seamless. For the detailed farm management information needed for the farm (and field) level modelling, no databases covering EU-25 or even EU-15 are presently available. The only EU-15 wide dataset that could provide more insight into farm management is the Land Use and Cover Areal Survey (LUCAS), but the quality of the data needs to be explored. Other options are project specific data such as data on typical farms from the International Farm Comparison Network (IFCN) or data on reference farms from the project European Livestock Policy Evaluation Network (ELPEN). However, these datasets only cover specific farm types and are not consistent across EU-25. Finally, it will be explored if national datasets that can be adapted for Seamless are available. Apart from the data availability problems the major problem in relation to the farming system data is the data are not spatially explicit, but normally only linked to administrative units such as NUTS2 or NUTS3 regions.

For the socio economic issues much consistent information is presently available for EU-25. The information is linked to administrative levels such as NUTS2 and NUTS3. It still needs to be specified to which degree the socio-economic data in SEAMLESS will be used for modelling or if the data will only be used to provide information in relation to assessments of model results and in relation to the development of socio-economic indicators.

The scope of the global analyses in Seamless is less ambitious than for the EU-level analyses. The analyses will to a very high degree be linked to the existing databases within the Global Trade Analysis Project (GTAP). The work in SEAMLESS in relation to the global data is therefore limited to updating and making minor additions to the existing data.

A general problem relates to the accessibility of data. Though no specific problems can be foreseen, difficulties might arise in relation to getting access to for example datasets aggregated from Member State level data with conditions attached in relation to third parties. We will seek to identify problems on data accessibility in the first phase of the project.

A major effort in the project will be to link all data within and between issues. Information on the different issues is rarely linked in existing databases and also within the different issues information at different scales is not linked. Tools such as typologies and aggregation/disaggregation rules have to be developed to remedy these shortcomings. The most important typology to be developed is the typology of farming systems that will be used to: 1) link modelling at the market-level to modelling at the farm (field) level and 2) link the information available in the EU-level databases to more imperfect information on detailed farm management practices. Furthermore, methods will be developed to locate the information on farm types spatially and enable a connection to environmental and socio-economic data. Furthermore, typologies will be developed that enable assessments of the performance of agricultural systems in relation to the systems environment, in environmental, social or economic terms.

Finally, transparency regarding the characteristics and limitations of the databases used will have a high priority. Comprehensive and consistent metadata describing the original databases, typologies, aggregation rules etc. will therefore be elaborated to be implemented in the SEAMLESS-IF.

3.9 Communication of results

Implementation of the sustainable development strategy requires fundamental changes in many sectors of our society, including agriculture and other land uses. Even if the

SEAMLESS project is primarily concerned with activities related to the use of agricultural lands, it must relate to many other sectors of our society. There are potentially many different kinds of stakeholders (e.g. farmers, consumers, food and transport industry) at many different levels (e.g. farm to EU and international). In order to successfully create a powerful planning tool like SEAMLESS-IF it is essential that key stakeholders are involved in the process in different ways. The first important consideration is that it must be possible to integrate SEAMLESS-IF into the existing planning and decision making process. The second consideration is that the results from SEAMLESS-IF must be compatible, or possible to harmonize with, the existing implementation structures of political decisions. In order to succeed in these two respects, a new form of knowledge production might be necessary. The scientific approach of SEAMLESS lends many of its ideas from the emerging field of co-evolution of knowledge presented in section 1.9.

Results from SEAMLESS can be described in simple terms as a very advanced tool for decision support. If used in the right way it will have the potential of strengthening the decision making process substantially. Apart from making the decision making more effective and sophisticated it will strengthen the power of the decision making bodies. This might be problematic from a democracy point of view. In order to provide a more level playing field for different stakeholders, the SEAMLESS-IF should be made available as widely as possible. We can foresee many different kinds of uses, such as:

- European Commission will use it for decision support when formulating strategies and policies.
- Different interest groups will use it for analyzing the consequences of a particular policy.
- National decision makers and planners will use it to facilitate the implementation of a policy.
- EU organizations will use it for sustainability impact assessments.
- NGOs will use it for lobbying purposes.

In order to reach out to as many potential users as possible, SEAMLESS needs to develop a portfolio of different communication methods and channels. The communication portfolio will consist of activities, products and services under the following three headings:

Interaction with users and stakeholders, including:

- workshops of different formats, lengths and scope for problem definition, co-learning, synthesis, dissemination and training;
- guidelines for participatory work during the development and proofs-of-concepts phase;

Communication with users and stakeholders, including:

- information products related to the research process, findings and products using different channels;
- web-page for dissemination of information as well as products;

Capacity building for effective implementation and use of the IF, including:

- network of users and stakeholders for proofs-of-concept and beyond;
- educational materials, including web-based tools, to be used in higher education and professional training throughout Europe and beyond.

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Appendices

Appendix I - Frameworks of indicator development

The target levels and Endpoint frameworks

One framework is based on the idea of defining target levels or endpoints of the assessed system .Indicator measures the closeness to a defined targett. The most commonly used approach (Michell *et al.*, 1995; Tschirley, 1997; Woodhouse *et al.*, 2000). This approach allows decision-makers to assess the gap between the actual state and the desired reference condition. There are two problem with this approach,the difficulty to defines the endpoint or target levels and the lack of incitement for proactive policy approaches.

The driving force- pressure-state-impact- response framework

Other frameworks are based on the "driving force- pressure-state-impact- response" model (DPSIR) This approach provides indicators that mainly target policy-makers or decision-makers. Both the European Union (Eurostat and EEA) and the United Nations as well as other international bodies (OECD, 1993; Jesinghaus, 1999; OECD, 2004) apply this framework as a basis for selecting their indicators on SD (UNCSD, 1996, 2001). . The DPSIR model classify indicators into driving force, pressure, state, impact and response indicators (Zander *et al.*, 2005). . Even though this approach is conceptually convenient and indeed popular, it does however exhibit a number of problems. One problem is that it reflects a sort of political end-of-pipe thinking that militates against more proactive responses encouraging short-term curative policies. Moreover, it has difficulty in capturing multiple causality and the interactions existing between indicators (Bell and Stephen, 2003).

The basic satisfaction framework

Another type of framework is the *basic satisfaction* framework. This framework rests on an analysis of what is deemed to be a basic necessity for SD as described by (Bossel, 1999). Indicators are selected on the basis of their ability to address a set of questions covering different aspects of sustainable development such as existence, effectiveness, security, adaptability and coexistence. The major problem with this framework is its apparent subjectivity and the fact that there is no immediate link between the indicator and the action.

A version of this type of framework is also used instead of comparing each indicator to some kind of general criteria they are related to a defined set of goals (Meter, 1999). Such a matrix of goals could for example focus on whether the indicators are linked to the issues that are important to a community or region which make this useful for showing whether the indicator measures the goals of SD that are actually important for a particular community. The major difficulty with this system is that it makes comparisons between different communities difficult.

The short and long-term framework

Yet another example of how indicators can be organised into a system is to make clear what can be done within the current time period and what should be left for future action. Such a framework highlights the longer-term aspects of sustainability. SD could in such a system be seen in terms of available capital (natural, human, social, physical and financial) and in a vulnerability context (trends, shocks and stresses) in which these assets exist (Woodhouse *et al.*, 2000). The major problem with this framework is the difficulty in evaluating both the available and future capital.

The four capital framework

Referring to the pioneer work of (Daly, 1973), (Meadows, 1998) proposes a framework which situates the human economy within a hierarchy resting on foundation of natural resources and reaching to the height of ultimate purpose.

According to (Meadows, 1998) sustainable development refers to the bottom and the top of the pyramid, the health of nature and well being of people, one measured in physical terms, one measured in subjective terms. Seemingly incommensurable the two faces of sustainability are linked through the intermediate steps.

Indicators can be derived from each level of triangle separately, but the most important indicators will reflect the connections between levels. (Meadows, 1998) proposes three aggregate indicators: real human welfare, environmental integrity and the ratio between them, which is the measure of efficiency with which environmental resources are translated into human welfare. Although the practical implementation of Daly-Meadows' framework might be difficult in SEAMLESS, the approach and structuring is inspiring. (Meadows, 1998) provides the list of potential indicators at each level of the pyramid as well as concrete aggregate indicators. Similar frameworks are used by the "four capitals" (economic, natural, human, and social capital) arising from the World Bank (Serageldin *et al.*, 1994), and the idea of "genuine savings." (WB, 1995).

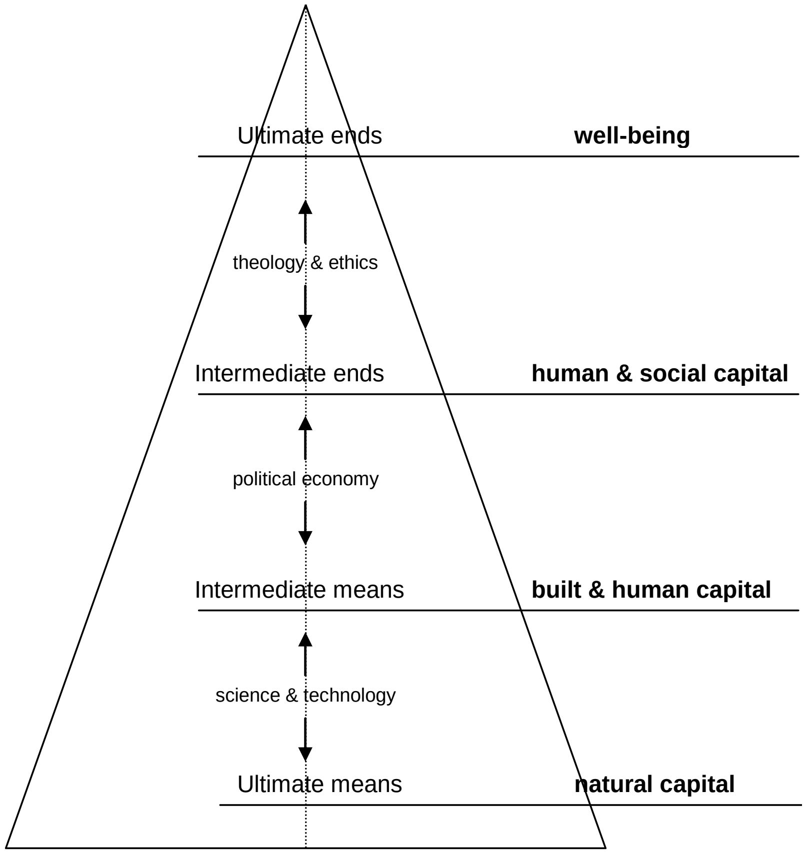

Figure A1. The Daly-Meadows Framework (Meadows, 1998).

Appendix II - Examples for user narratives

1. WTO negotiations and sugar prices

What will happen if all EU subsidies and trade limitations on sugar are lifted in the November 2005 WTO Hong Kong Round? There will be consequences in EU regions producing sugar both directly in terms of farmers' responses and indirectly in terms of industrial and transport changes. There may also be effects outside the EU in terms of increased income opportunities in developing countries. This might be interpreted as if the EU agriculture contributes to sustainable development outside EU.

1. What will happen to the price of sugar?
2. How much sugar will be produced in EU?
3. Where in the EU will sugar be produced and where will production cease?
4. How much sugar will be imported?
5. How will agriculture in the developing countries be affected by the change in sugar policy in EU?
6. Will this contribute to poverty reduction in developing countries?
7. How many sugar factories in EU can stay in business?
8. Which sugar factories in EU will likely discontinue?
9. How many workers will be unemployed due to the closing of sugar factories?
10. How many hectares of sugar beet will be planted in EU?
11. What other crops will be grown instead of sugar beet?
12. What will happen to the price of these crops?
13. What will be the leakage of N and P from agricultural land?
14. In what way will biodiversity be affected?
15. If sugar becomes cheaper, how will that affect consumer behaviour?
16. If it is decided to replace fossil fuel by bio-energy at a large scale, how much can sugar beets contribute in the form of ethanol?
17. Will the ethanol be competitive in relation to other bio-energy sources and in relation to imported ethanol?

2. What will happen if the Water Framework Directive is implemented?

As the Water Framework Directive (WFD) is a directive it is up to the member states to implement it in a flexible way, as long as it contributes to improved water quality in Europe. The type of implementation and its results will depend on the quality aspect of water which is most crucial, and hence differs between countries and regions within countries. Results of the implementation will strongly depend on behaviour of actors that do or do not respond to the regulations.

To limit the scope of the "narrative" we will here focus on a rise of the price of water, which is an option put forward by several member states[1]. There will be consequences in EU regions both directly in terms of farmers' use of water and indirectly in terms of changing patterns of competition and perhaps choice of crop. There may also be effects outside EU in terms of increased income opportunities in developing countries but increased environmental pollution.

1. What will happen with the consumption of water and groundwater?
2. What will happen to the prices of agricultural commodities?
3. How much will be produced in EU?
4. Will farmers change to less water consuming production?

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[1] However some countries have solved the problem in a slightly different way and for those countries that will start to prize water it is still unclear in which way this will be done something that definitely will influence the outcome response of farmers and effect on water quality.

5. Will some production/crops be (dis)favoured?
6. Which new production/crops will be (dis)favoured?
7. What will happen with the use of pesticides?
8. What will happen with the use of commercial fertilizers?
9. What will be the major regional differences in effects across the EU?
10. How will developing countries be affected by the change in water price in EU?
11. Will this contribute to poverty reduction in developing countries?
12. Which farm types in developing countries will benefit from an increased production of certain products?
13. In what way will bio-diversity be influenced?
14. What will happen with the leakage of P and N?
15. What will happen with the leakage of pesticides?
16. What will happen with erosion?
17. What will happen with salinisation?
18. How will this influence energy consumption?
19. How will traditional crops and ways of production be influenced?
20. How will different farm types across the EU be influenced economically?
21. How will unemployment among farmers be influenced?
22. *How will this influence the food industry?*
23. How will this influence the prices of food?

3. Agro-technological innovations

What will happen if new technologies become available or will be permitted due to changes in EU-legislation, for instance organic production methods, GMOs with herbicide resistance, conservation tillage methods, conservation methods to enhance functional biodiversity and birdlife such as agro-forestry, intercropping, crop rotation and grass strips?

Which policies will be successful in stimulating adoption of such new technologies (e.g. cross-compliance policies) and what will be the result in terms of economic, environmental and social aspects of sustainability at different scales? Let us assume we assess adoption and consequence of a concrete set of new technologies:

1. Which of the proposed technologies are likely to be adopted under baseline conditions by which farm types?
2. What are the main factors determining adoption: risk attitude farmers, prices (of either inputs or outputs), taxes on input, taxes on level of pollution, institutional factors?
3. How do the property rights structures of the natural resources affected by the new technologies and the effective (formal and informal) governance structures in place impact on the adoption of farmers?
4. Is the ‘institutional capacity’ favourable for the technical adoption?
5. What will be the impact of adoption for specific farm types in specific regions (in e.g. France and Poland), in terms of economic, social and economic indicators?
6. What will be the aggregate impact at EU level (including feedback mechanisms via markets) in terms of economic, social and economic indicators?
7. Which type of farms will increase/decrease in frequency?
8. What will be the impact of adoption of these technologies on the major crops and animal production in EU and in specific regions (area and locations)?
9. Do (possibly new) cross-compliance policies enhance the uptake of new technologies?
10. Do the new technologies contribute to landscape quality and biodiversity and if so how?
11. What is the effect of new technologies (and their adoption) on the competitive position of the EU versus the US and Australia?

12. What will be the impact of adoption of these technologies on labour requirement in agriculture?
13. *What will be the impact of these changes in agriculture on quality of life and human welfare in rural areas?*

4. Effects of cross-compliance policies on sustainable development

Cross-compliance is introduced in the EU to improve compliance with existing standards in the field of environment, nature, food safety, animal welfare and health. The second objective is to ensure, through the establishment of codes of 'good agricultural conditions' that decoupling of direct payments from production does not lead to environmentally damaging marginalisation or abandonment. What will happen to the further integration of environmental concerns in the CAP?

1. What is the value-added from cross-compliance as a tool to improve compliance with existing standards, both environmentally, economically and socially?
2. What environmental benefits are achieved through cross-compliance?
3. What farm types might be affected most by cross-compliance?
4. What are the cost implications and competition effects resulting from either enforcing previously ignored standards or rules of 'good agricultural practices'?
5. What are the differences between different alternative cross-compliance policies comparing costs for obtaining similar results in terms of environmental results?

For the concrete case of cereals and oilseeds sector:

6. Can cross-compliance ameliorate the compliance respect the Nitrates Directive? [not clear]
7. What will be the impact on bio-diversity of the condition imposed to cultivate at least three different crop species by farm?
8. How important will the impact of the buffer strips be in environmental terms to limit water pollution?

5. Climate change mitigation and agriculture

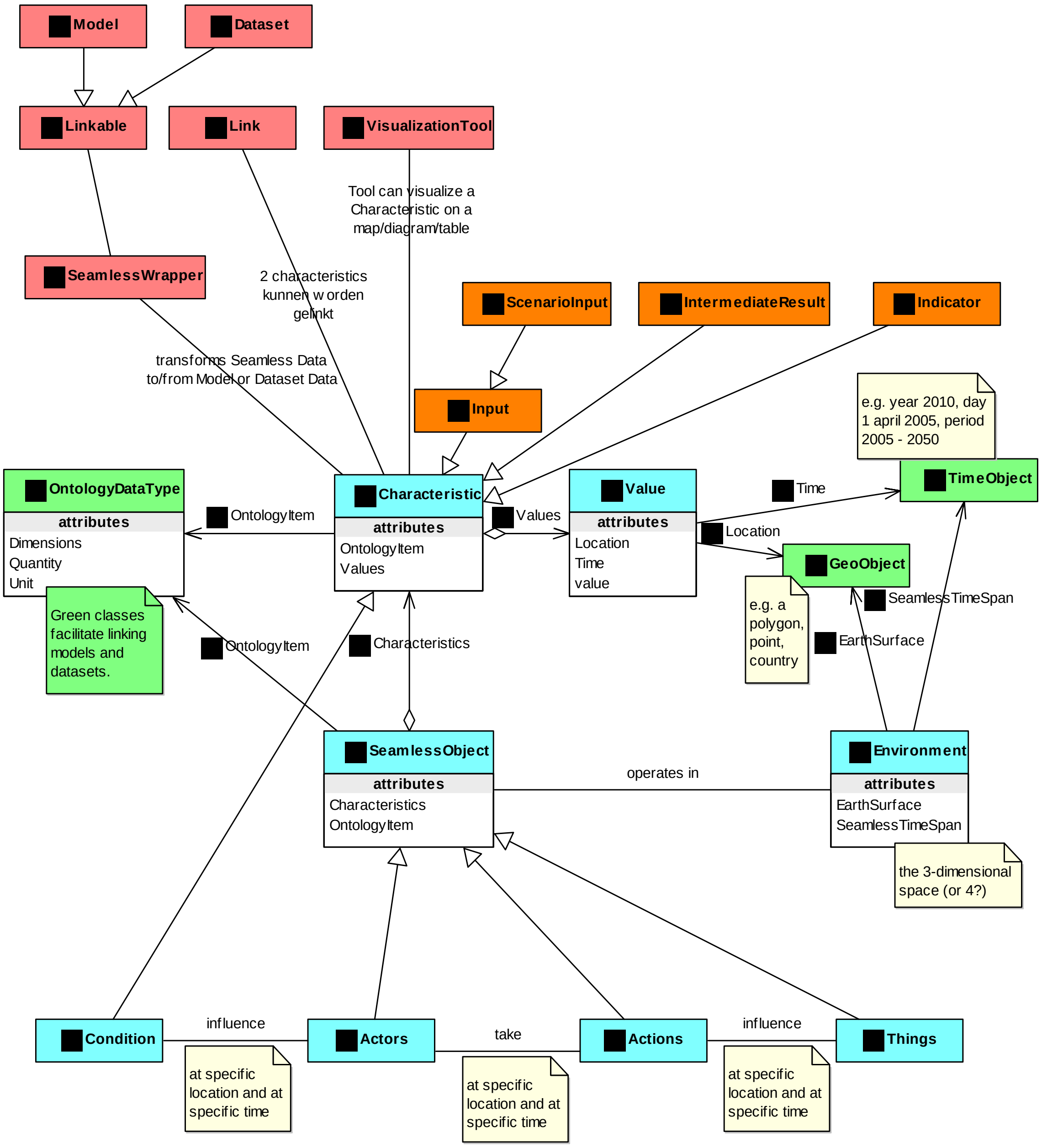
Let us assume the EU decides to cut emission of greenhouse gases by 30% in 2020 and 60% in 2050. The agricultural sector can potentially contribute to substitute some of the fossil fuels that will be phased out. The agricultural sector also needs to reduce its own emissions of CO_2, methane and nitrous oxide. The landscape itself might also contribute by sequestering CO_2. This theme could result in the following questions with relationships to policy development:

2. How much energy can be produced in the agricultural sector?
3. *Which forms of energy (biomass, ethanol, methanol, biogas, ….)?*
4. In which regions would this be an interesting option?
5. Which energy security could be attained (climate variation and climate change)?
6. How would this affect food production?
7. How would this affect processing of agricultural products in the food industry?
8. How would this change the European landscape?
9. *Which trade offs exist with other land uses (recreation, food, water, biodiversity)?*
10. How would this affect options for future food production (through soil processes)?
11. If European agriculture shifts to energy production, how would this affect other countries outside EU?
12. How much carbon could be sequestered in European agricultural soils?
13. What kind of changes in land use and cropping practices would be required?
14. Where in EU would this be an interesting and cost effective option?
15. Could soil carbon sequestration also contribute to other environmental and social goals (biodiversity, recreation, clean water provision)?

16. Would a shift from food production to energy production (or carbon sequestration) be socially acceptable to people?
17. How would this affect the cultural heritage of European landscapes?
18. How much more energy efficient could European agriculture be?
19. If local production is promoted, will that be in conflict with other political goals (e.g. European integration)?
20. Will a shift from food to energy production/sequestration have ramifications for the labour market (more or less job opportunities)?
21. When/if carbon neutral energy carriers become operational, will it be possible to return to food production?

Appendix III – Representation of the combined SeAM model

The SeAM models are different (orthogonal) views of the modeling system. It is important to recognize how the models relate. The concepts in the subdomains are summarized in the figure below.



Blue objects relate to concepts in the business (i.e. Seamless) domain. Actors (farmers, consumers), Actions (irrigating, consuming), Things (= everything which is not an actor: products, crops, soil, weather, etc) are SeamlessObjects. Each SeamlessObject has characteristics (or attributes or properties. e.g. temperature, soiltype, landuse, price). A SeamlessObject always is and/or operates in an environement somewhere on the earth at a certain time. A condition is a specific characteristic. Characteristics have values which are valid in a specific time in a specific place (temperature = 20 degrees celsius on 1st april in France).

SeamlessObjects and their Characteristics have a reference to a SeamlessOntologyItem. A SeamlessOntologyItem is the ‘thematic’ dimension and refers to a concept in the business domain (the agri-environmental domain). This is needed to unambigously define all concepts in Seamless-IF. SeamlessObjects can be used to group different Characteristics (e.g. a sugar is a seamless object and has as characteristics a price, amount produced, amount imported). (Remark on UML diagram: Unit and quantity would not be relevant for the OntologyItems of SeamlessObjects).

Green objects are the dimensions of the environment and are indispensable for the linking of models and datasets. Furthermore, you can use this information to visualize the values on a map or time-graph. Also you can use this information to search for specific indicators or other information in Seamless-IF.

Orange objects relate to the conceptual model of the analysis domain. In a workflow process within SEAMLESS a user can search for indicators, choose a region, choose a time, set scenario-inputs and view the results. (S)he can do all these things with the Characteric object, because the Characteristic object knows what it is (a price, a soilcharacterstic, etc) because of its reference to an ontologyitem and it knows where and when.

Red objects relate to the conceptual model of the modelling domain. Seamless-IF should be able to link Characteristic Objects, visualize them or do other general operations on them (like up-and-down scaling). Models and datasets need a wrapper, so that you know what type of data goes in (a reference to an ontologyItem) and what type of data goes out (also a reference to an ontologyItem). Also datasets should be able to tell where and when the data are valid. Models should be able to accompany their output data with location and time (they might just have to pass on this metadata from their inputs).