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Abstract: Agricultural systems continuously evolve and are forced to change as a result of a range of global and local driving forces. Agricultural and environmental policies are increasingly designed to contribute to the sustainability of agricultural systems and to enhance contributions of agricultural systems to sustainable development at large. The effectiveness and efficiency of such polices in realizing desired contributions could be greatly enhanced if it were possible to perform ex-ante assessments. The European Commission has recently introduced impact assessment of its policies as an essential step in policy development. This paper presents the design and first prototype of a computerized integrated framework to assess, ex-ante, agricultural and environmental policies across a range of scales, from field-farm to region, EU25 and globe. In this large integrated project 30 research groups work jointly on developing the SEAMLESS Integrated Framework. Key requirements of the framework are that it is open, generic and transparent. This puts stringent requirements on the software backbone of the project and on a modular set-up. The framework is developed in close interaction with the targeted prime users, including the European Commission.

Keywords: integrated assessment, sustainable development, agricultural systems, software framework, model components, ontology

1. INTRODUCTION

Agricultural systems around the globe continuously change as a result of enlarging trade blocks, globalisation and liberalization, introduction of novel agro-technologies, changing societal demands and climate change. Despite the trend for liberalization, there is consensus in the policy domain that policies are needed to support sustainability within the agricultural sectors and even more importantly to enhance the contribution of agricultural systems to sustainable development of societies at large. Agricultural, environmental and rural development policies must contribute to these aims, in a cost-effective and efficient manner. Assessing the strengths and weaknesses of new policies prior to their introduction, i.e. ex-ante integrated assessment, is vital to target policies at sustainable development. The European Commission, for instance, has introduced Impact Assessment of its policies as an essential step in the development and introduction of new policies since 2003 (EC, 2005). It explicitly calls for assessment of the economic, environmental and social impacts of policies and consultation with stakeholders. By nature it implies a demand for multi- and interdisciplinary research and tools, which allow inclusion and evaluation of views of different stakeholders.

Today actual use of research tools in the policy domain for impact or integrated assessment is still limited. Most of the approaches developed by research which could potentially play a role are still largely disciplinary and focused on specific issues and hierarchical levels. Hence their use to assess policies and innovations, which by definition affect different hierarchical levels (e.g. the globe, developing countries, EU25, administrative region in a country, specific farms and fields) and across economic, environmental and social domains, is restricted. The gap between analysis at micro level (farms) and macro level (region or market) is still largely unresolved. Also, as most of the research models are issue-specific, possibilities for re-use in other assessments are limited, whereas political agendas can evolve rapidly. A further issue that limits *integrated* use of different research models and tools is their ad-hoc solutions in terms of software. Naturally this has a strong impact on the possibility to re-use existing research tools and to maintain them. Lastly, end users and the way they will use the tools are often not clearly identified and determined.

Integrated assessment and modelling (IAM) has been proposed by research as a means of enhancing the management of complex environmental systems. It is based on systems thinking and a way to consider the different aspects (biophysical, institutional, social and economic) of a system under study (Harris, 2002; Parker et al., 2002). IAM is an analytical approach that seeks to gain insight from the analysis of interactions. IAM 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).

The current paper introduces and presents the aims of the SEAMLESS Integrated Framework (SEAMLESS-IF) for an ex-ante, integrated assessment of agricultural and environmental policies and agro-technical innovations in the EU25. SEAMLESS stands for System for Environmental and Agricultural Modelling; Linking European Science and Society. The main features of its first prototype are presented.

2. SEAMLESS INTEGRATED FRAMEWORK (SEAMLESS-IF)

2.1 Aims of SEAMLESS-IF

SEAMLESS aims at developing a computerized, integrated framework (SEAMLESS-IF) to assess and compare, ex-ante, alternative agricultural and environmental policy options, allowing:

1. Analysis at the full range of hierarchical levels (farm to EU and global), whilst focusing on the most important issues at each level;
2. Analysis of the environmental, economic and social contributions of a multifunctional agriculture towards sustainable rural development.
3. Analysis of a broad range of issues and drivers of change, such as climate change, environmental policies, rural development options, an enlarging EU, international competition and effects on developing countries.

SEAMLESS-IF will have the following specific features and capabilities:

1. A multi-perspective set of economic, social and environmental indicators of the sustainability and multifunctionality of systems, policies and innovations in agriculture and agroforestry, derived through so-called indicator frameworks facilitating interactive and systematic selection of indicators with users and stakeholders.
2. Quantitative models, tools and databases for integrated evaluation of agricultural systems at multiple scales and for varying time horizons.
3. A software architecture, SeamFrame, that allows reusability of indicators, models, data and knowledge, also ensuring transparency of models and developed procedures.

SEAMLESS-IF is applied and tested in two Test Cases, one focusing on assessment of Common Agricultural Policy reforms and trade liberalisations as a consequence of WTO negotiations, and a second on assessing local implementations of environmental directives and consequences of agro-technical innovations.

In short, SEAMLESS-IF aims to facilitate translation of policy options into alternative scenarios that can be assessed through a set of indicators that capture the key economic, environmental, social and institutional issues of the questions at stake. The indicators in turn are assessed using selected linkages of quantitative models. These models have been designed to simulate aspects of agricultural systems at specific levels of organisation, i.e., point or field scale, farm, region, EU and world. SEAMLESS aims at an integrated use of these, partly, existing models. SEAMLESS also assembles pan-European databases for environmental, economic and social issues. Some indicators, particularly social and institutional ones, will be assessed directly from data.

Linkage of models designed for different scales and from biophysical and economic domains requires software architecture, and a design and technical implementation of models that allows this. The software backbone of the project, SeamFrame, serves that purpose.

Scientifically, the project aims at facilitating a breakthrough in the integrated use of models, enabling scaling. It targets at a modular approach ('mix-and-match') and an open source software architecture that allows use and re-use models, databases and scenarios in the domain of agricultural systems.

2.2 Users of SEAMLESS-IF

SEAMLESS-IF adopts a participatory development trajectory. Within the project with its 30 partners and 150 researchers from a broad range of disciplines this is done through working with Prototypes and iterative cycles of requirements analysis, testing and improving. In parallel, Prime Users (Directorates General of the European Commission) are involved in this process through a User Forum. The User Forum was established after an initial phase of bilateral contacts and interviews, as well as small meetings. In the design of SEAMLESS-IF six classes of users are distinguished, i.e., coders, linkers, runners, providers, viewers and players, with distinct user requirements.

3. SeamFrame SOFTWARE ARCHITECTURE

The main philosophy of SeamFrame is to create a coherent simulation system by re-using a variety of available, so-called 'sources', such as models, databases, expert rules and analysis tools. All

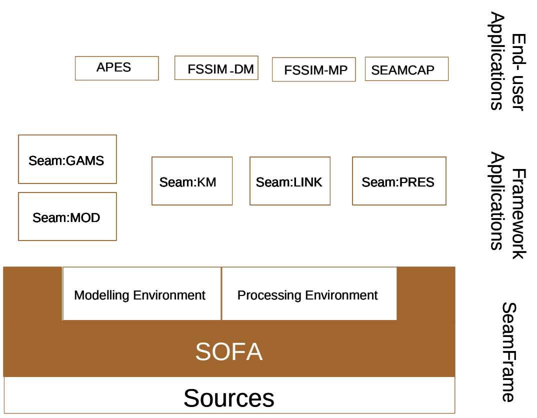

Figure 1. SeamFrame architecture, its framework applications and end-user applications

sources need to implement a standard interface. Figure 1 provides a schematic overview of the overall design and its stacked component architecture. SeamFrame is build upon the OpenMI 1.0 standard (www.openmi.org). To facilitate mixing these sources, SeamFrame incorporates domain knowledge and semantic meta-information. This allows for checking the match between sources. This mix-and-match philosophy is embedded in the SEAMLESS OpenMI+ Framework Architecture (SOFA) which forms the software spine of SeamFrame. It facilitates both system development and system evaluation. With SeamFrame, any 'source' that implements the OpenMI interface can be linked. It is envisaged that tools will be added for cross-model debugging and sensitivity analysis covering the whole chain of models.

SeamFrame will guide users choosing the appropriate models, model/tool combinations and data bases for the various policy evaluations of agricultural systems. SeamFrame will provide a set of pre-packaged applications for these decision makers, and a graphical user interface. Users belonging to the class coders, linkers or runners, however, will use the modelling environment to create and adjust models and data. Such scientific tasks will be achieved using components from the component toolbox: knowledge manager, a tool for data and ontology manipulation, and the modelling environment, for creating and editing executable models. In Prototype 1 the overall architecture of SeamFrame was designed, initially implemented and populated with first essential components and applications (see Section 5). Semantic meta-information is organised in the knowledge manager (Seam:KM) using the first draft ontology for data and models (Athanasiadis et al., 2006; Villa et. al., 2006). Also the design to integrate modelling environments within SeamFrame is made (allowing to 'plug-in' alternative modelling environments), with as current choices MODCOM (Seam:MOD) for biophysical models and GAMS (Seam:GAMS) for farm economic and market models. The thus created model-chain is deployed in the processing environment. SeamFrame is developed using an architecture centred software development process allowing a staged delivery of pre-existing or new and enhanced components (Van der Wal et al., 2005).

4. INDICATOR FRAMEWORK

Baseline and policy scenarios are assessed and compared in SEAMLESS-IF through their characterisation by a set of indicators. These indicators must capture the main features of interest to users and stakeholders, about the economic, environmental, social and institutional issues at stake. So-called indicator frameworks are developed to structure a broad range of indicators and to facilitate their interactive selection by stakeholders and users. Discriminating classes of the initial indicator framework as listed in Table 1. Indicators are assessed either through quantitative model components (next section) or directly through data or semi-quantitative procedures (cf. social and institutional indicators).

Table 1. Discriminating classes of initial indicator frameworks. Within Prototype 1 SEAMLESS-IF uses two classes, i.e., Dimensions of sustainability and Levels of organisation.

Dimensions of sustainability
- biophysical, economic, social, institutional
Levels of organisation
- field, farm, region, EU25, globe
Domains
- sustainability, sustainable development
Themes
- goals, process of achievement, means
System's properties
- viability, performance, capital, maintenance

5. MODEL COMPONENTS

5.1 Introduction

The first prototype of SEAMLESS-IF includes an indicator calculator which draws information from a model chain to compute selected indicators. The model chain (Fig. 2) comprises the agricultural sector model CAPRI that simulates supply-demand relationships in the EU25 for agricultural commodities; CAPRI derives information on price-supply relationships from farm system models (FSSIM) through an econometric procedure (EXPAMOD). The farm models in turn simulate farm behaviour and use agricultural activities (e.g. crop rotations) assessed through a mechanistic simulation model for agricultural production and externalities (APES). Indicators can be assessed through CAPRI, FSSIM and APES, each at specific scales.

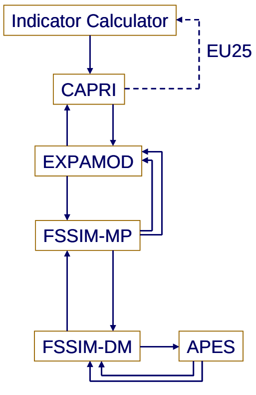

Figure 2. Models and model chain in Prototype 1 of SEAMLESS-IF.

5.2 Agricultural Production and Externalities Simulator (APES)

APES is a modular simulation model estimating the biophysical processes of agricultural production systems, at **point level**, in response to weather and different options of agro-technical management (cf. Van Ittersum and Donatelli, 2003). The processes are simulated in APES with deterministic approaches mostly based on mechanistic representations of biophysical processes. This is done for a variety of regional specific climatic conditions and soils. APES will compute the yields, as well as several inputs and externalities of crop rotations; both averages and variability across years will be generated. Currently first versions of weather (Donatelli et al., 2006), crop, grassland, and soil water and nitrogen components of APES have been developed.

5.3 Farm System SIMulator (FSSIM)

FSSIM (Farm System Simulator) is a bio-economic farm model developed to quantify the integrated agricultural, environmental and socio-economic aspects of **farming systems**. FSSIM includes a data module, FSSIM-DM, which computes the technical coefficients for agricultural activities and FSSIM-MP, the mathematical programming part of the model to capture constraints and objectives (Deybe and Flichman, 1991; Janssen and Van Ittersum, 2006).
Applied at farm (micro) level, FSSIM seeks to represent the actual farmers' behaviour using the knowledge of technical and socio-economic constraints, the relation between production factors, the amount of output obtained and the costs of each production activity (= cultivation of a crop rotation or livestock system in a specific environment) and future market prices. This type of models adopts a primal approach for describing the technology, applying production functions, partly derived from APES. FSSIM also uses information from statistical databases and expert knowledge for assessment of current activities. For assessing alternative activities, the following generators have been developed: Production Enterprise Generator which generates alternative crop rotations; Production Technique Generator which generates alternative production techniques; Technical Coefficient Generator which computes the technical and economic coefficients for the mathematical programming model. First versions of these generators and a template for the mathematical programming model of FSSIM have been designed and implemented in SeamFrame.

5.4 Agricultural Sector Model (CAPRI)

CAPRI *(*Common Agricultural Policy Regionalised Impact) is an **Agricultural Sector** model of the European Union (Heckelei and Britz, 2001). It is a comparative static equilibrium model, solved by iterating supply and market modules. The supply module consists of 250 regional non-linear programming models with a highly differentiated set of activities allowing direct implementation of most domestic policy measures. Allocation is based on profit maximising behaviour and calibrated multi-product cost functions. CAPRI also estimates regional nutrient balances and gas emissions with global warming potential using a matrix of coefficients linked with regional activity levels. The CAPRI market module endogenously adjusts EU- and international prices to achieve market equilibrium. It also allows to asses the impact of represent a large set of bi- and multilateral trade policy instruments..

5.5 Econometric upscaling procedure for micro-macro linkages (EXPAMOD)

The methodology envisaged to map the **supply behaviour** of farm models (FSSIM) to the market model (CAPRI) comprises the following sequence of steps: 1) Simulation of FSSIM supply response to price variations to obtain price-quantity data set; 2) Estimation of an econometric Meta-model explaining supply response based on explanatory variables, which determine FSSIM supply response, but are also available for the whole EU. 3) Use of this Meta-model (EXPAMOD) to extrapolate supply response to other farm types and regions. 4) Aggregation of supply response to level of CAPRI regions (administrative units). 5) Calibration of regional supply modules in CAPRI to aggregated supply response.

5.6 Anticipated model components to be integrated in later prototypes

Next prototypes of SEAMLESS-IF are anticipated to include the following components:

- Territorial models that enable assessment of environmental and biodiversity indicators, as well as visual quality of the landscape at regional and lower levels.
- Rural employment model: an econometric approach to assess effects of policies on agricultural employment at EU25 and lower levels.
- GTAP: a global trade (computerized general equilibrium model) model, including global database of production and trade, to analyse the impacts of EU policies on the rest of the world (Van Tongeren et al., 2001).
- Developing country models: computerized general equilibrium model at national level linked to farm household models (FSSIM) to allow for assessing effects of EU policies on agricultural production, environmental impacts, poverty and rural development in developing countries.

6. DATA AND TYPOLOGIES

In Prototype 1 first versions of pan-European databases are available as ‘Sources’ (Fig. 1) for: environmental data (soils, altitude and climate), farming data and socio-economic data.
It is a major objective of the project to include data that can be distributed freely. This means that it is not always possible to include the original data sets in SEAMLESS-IF due to property rights and, in some cases, disclosure rules. For spatial data it is therefore in some cases necessary to transform the original data from vector data to grid data or to a lower spatial resolution. For thematic data it is likewise possible to distribute some data only in aggregated format, for example by building typologies of farms rather than distributing single farm data.
Another major objective is to link the different types of data, for example data from farm statistics, data on the biophysical environment and socio-economic data. This will be done by making all data spatially explicitly linked to a 1x1 km^2 grid, i.e. all data are available for that level, although the spatial resolution for e.g. socio-economic data is much less. A specific achievement in relation to this is the development of a statistical procedure to distribute the information from farm economic statistics available for administrative regions to biophysical units with similar conditions for crop production.
Closely linked to this, and to enable upscaling through statistical sampling procedures, typologies are being developed for farming systems (based on farm size, specialisation, intensity and land use; Andersen et al., 2006), the bio-physical environment (climate, soil, northing and oceanity) and socio-economic characteristics (population density, income, etc.). These typologies will also provide a useful context to assess indicators coming from the modelling results.

Datasets are currently characterised by metadata (ISO-standards). Data are linked to models through the use of the initially drafted ontology. This enables future users to get interactively insight in the quality of the stored data and to identify appropriate use of the data. Additionally, information will be included in the databases that allows the user to explore the uncertainty related to the data. This is crucial, especially for aggregated data, to assess the robustness of the final model results. Finally, tools and procedures for updating the data will also be included in SEAMLESS-IF to allow future users to incorporate more recent information.

7. CONCLUSIONS

SEAMLESS targets at a working version of the integrated assessment framework by 2008 for its Prime users in the European Commission. At the same time the software backbone of the project, SeamFrame, is anticipated to provide an open source means to facilitate integration of models and other knowledge sources from different domains and programmed in different environments and languages. Finally, the different components of SEAMLESS-IF are designed to have standalone value. These components can be used for targeted applications or serve as a starting point for further scientific development. As such, we aim that the integrated framework facilitates condensation and synthesis of scientific knowledge in the domain of agriculture and its environment.

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