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Defining assessment projects and scenarios for policy support: Use of ontology in Integrated Assessment and Modelling ☆

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ABSTRACT

Integrated Assessment and Modelling (IAM) provides an interdisciplinary approach to support ex-ante decision-making by combining quantitative models representing different systems and scales into a framework for integrated assessment. Scenarios in IAM are developed in the interaction between scientists and stakeholders to explore possible pathways of future development. As IAM typically combines models from different disciplines, there is a clear need for a consistent definition and implementation of scenarios across models, policy problems and scales. This paper presents such a unified conceptualization for scenario and assessment projects. We demonstrate the use of common ontologies in building this unified conceptualization, e.g. a common ontology on assessment projects and scenarios. The common ontology and the process of ontology engineering are used in a case study, which refers to the development of SEAMLESS-IF, an integrated modelling framework to assess agricultural and environmental policy options as to their contribution to sustainable development. The presented common ontology on assessment projects and scenarios can be reused by IAM consortia and if required, adapted by using the process of ontology engineering as proposed in this paper.

1. Introduction

Integrated Assessment and Modelling (IAM) is increasingly used to assess the impacts of policies, technologies or societal trends on the environmental, economic and social sustainability of systems (Harris, 2002; Parker et al., 2002; Oxley and ApSimon, 2007; Hinkel, 2009). Prominent examples are the assessment of climate change impacts (Weyant et al., 1996; Cohen, 1997; Warren et al., 2008) and the assessment of quality and allocation effects in water resource management (Turner et al., 2001; Letcher et al., 2007; Ticehurst et al., 2007). Integrated assessment is defined by Rotmans and Asselt (1996) as an interdisciplinary and participatory process of combining, interpreting and communicating knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena. IAM is then a methodology to combine several quantitative models representing different systems and scales into a framework for integrated assessment (Parker et al., 2002). Consequently IAM can cover several organisational and spatio-temporal scales to provide quantitative assessment of impacts on sustainable development.

Core features of any IA are the integration among disciplines and between scientists and stakeholders (Rotmans, 1998; Parker et al., 2002). Scenario analysis is an important technique in integrated assessment (Rotmans, 1998), where scenarios are developed and used in the interaction between scientists and stakeholders to

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anticipate and to explore possible futures and to assess potential consequences of different strategies into the future. The literature provides many different definitions of the concept scenario. For example, Rotmans (1998) defines scenarios as 'archetypal descriptions of alternative images of the future, created from mental maps or models that reflect different perspectives on past, present and future developments,' while Parry and Carter (1998) define a scenario as 'a coherent, internally consistent and plausible description of a possible future state of the world.' In strategic business planning, where scenarios are often used as planning tool, scenarios are defined (according to Schoemaker, 1993) as 'focused descriptions of fundamentally different futures presented in a coherent script or narrative.' Peterson et al. (2003) provide a definition of scenario which is closer to modelling, i.e. 'as variation in the assumptions used to create models.'

Next to a wide range of definitions for scenarios, also different classifications and typologies of scenarios exist (Rotmans, 1998; Greeuw et al., 2000; Alcamo, 2001; Van Notten et al., 2003; Borjeson et al., 2006): forecasting vs. backcasting scenarios, descriptive vs. normative scenarios, quantitative vs. qualitative scenarios, trend vs. peripheral scenarios, baseline vs. policy vs. business-as-usual scenarios and exploratory vs. anticipatory scenarios. A wide diversity of terms are associated with scenarios, such as indicators, driving forces, time horizon, time steps, storyline or narrative, processes, states, events, consequences and actions. It is not clear how these classifications and terms relate to each other and how they are used in constructing scenarios for IA.

Confusion and misunderstanding are particularly high when it comes to the implementation of scenarios. A researcher who is working in an IAM team, will be confronted with different types of stakeholders and scientists, with the latter covering a wide variety of disciplines and experiences. Each scientist will have a specific understanding of the concept scenario which is not consistent across disciplines and models. Discussions among scientists from different disciplinary domains and stakeholders are likely to result either i) in developing a 'container' term for scenario which serves as the magical solution whenever researchers are unclear about the way forward, or ii) in lengthy discussions on the meaning of scenario without arriving at any conclusion acceptable to the whole group. Again, the critical issue is that different models and policy problems have a specific implementation of scenarios targeted at that specific model or policy problem. There is a need for a clear set of rules and protocols with respect to scenarios in IA, as concluded by Rotmans and Asselt (1996), to avoid the danger of in-transparent, inconsistent, narrowly defined and ad-hoc setting of parameters (Rotmans, 1998; Van Asselt and Rotmans, 2002).

This paper considers a case study of achieving consensus on scenario definition in an IAM consortium, System for Environmental and Agricultural Modelling; Linking European Science and Society (SEAMLESS) (Van Ittersum et al., 2008). It provides a computerized framework (SEAMLESS-IF) to assess the sustainability of agricultural systems in the European Union at multiple scales. The SEAMLESS consortium includes 30 institutions and more than 100 researchers from agronomy, economics, landscape ecology, social science, environmental science and computer science with dissimilar research background, leading to many different views on the meaning of scenario and its implications for the computerized integrated framework (SEAMLESS-IF). For example, biophysical simulation models (Van Ittersum and Donatelli, 2003) used for climate change impact assessment often apply the SRES scenarios framework (IPCC, 2000). In contrast, in a market model (Britz et al., 2007) a scenario typically refers to a policy that might be implemented in the future and that affects the market.

This paper proposes a unified structured view for model-based scenario and assessment projects and a process of arriving at this result within a large community of researchers in a consortium. We demonstrate the use of common ontologies (see Section 2 for explanation) in building this shared conceptualization through a case study. This paper describes our experiences in the challenging task of arriving at a shared conceptualization among researchers from different disciplines with dissimilar education and research experiences. We suggest that the process and the methods used are reusable for different integrated assessment tools or consortia developing such tools.

In Section 2, the theory behind common ontologies and the process of ontology engineering will be explained. Also, our case study based on the SEAMLESS consortium is introduced. In Section 3, the developed common concept on scenario and assessment projects is presented, including one fictitious example of the use of the common concept in an integrated assessment project at the regional scale. The common concept is discussed in Section 4. In Section 5 we address our main findings as to the unified structured view on scenarios and assessment projects that we propose in this paper. Throughout the paper, we list some of the lessons we learned in our exercise to achieve this common understanding.

2. Materials and methods

2.1. Ontologies

In the context of integrated modelling, ontologies are useful to define the shared conceptualization of a problem. Ontologies consist of a finite list of concepts and the relationships among these concepts (Antoniou and van Harmelen, 2004; Fig. 1) and are written in a language, e.g. Web Ontology Language (McGuinness and Van Harmelen, 2004), that is understandable by computers. The term ontology originates from philosophy and was coined by classical philosophers Plato and Aristotle in the study of types of being and their relationships (metaphysics). An ontology in computer science is considered as a specification of a conceptualization (Gruber, 1993), where a conceptualization is 'an abstract, simplified view of the world that we wish to represent for some purpose' (Gruber, 1993). A computer can understand an ontology, because it is structured according to concepts and relationships on which it can reason, as opposed to unstructured files like documents or html (Antoniou and van Harmelen, 2004; Fig. 2). This difference is illustrated in Figs. 1 and 2. Fig. 1 can be understood by a human, while Fig. 2 can be understood by computers. Applications of ontologies are known in the field of medical research (e.g. Musen, 1992; Flanagan et al., 2005) for lexicon or taxonomy-like descriptions of diseases or the genome, and computer science (e.g. Antoniou and van Harmelen, 2004) for information and document management.

Scientists from various disciplines can define a common conceptual schema that their domains share as a basis for the integration of their models. A common assessment project ontology, i.e. an ontology which is shared by all domains considered for integration, serves as a knowledge-level specification of the joint conceptualization, in our case of the project and scenario definition. Each scientist can refer to and must adhere to the semantics of the concepts in the assessment project ontology, including restrictions on the concepts and relationships between the concepts.

2.2. Process of ontology engineering

The process of ontology engineering consists of set-up, design, approval and dissemination phases. In the set-up phase, the need for a common ontology is

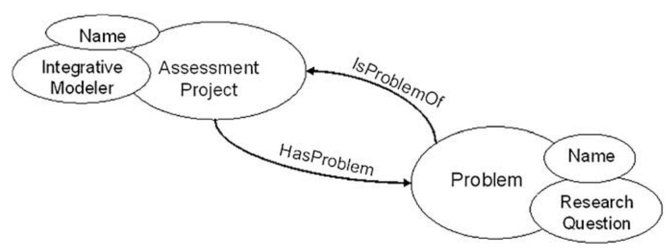

Fig. 1. A part of an ontology showing two concepts (in ovals; Assessment Project and Problem), their relationships (uni-directional arrows; relationship as Assessment Project has Problem and relationship as Problem is Problem of Assessment Project) and their data-properties (Name for Concept Assessment Project and Problem, Integrative Modeller only for Concept Assessment Project and Research Question only for concept Problem).

```
<owl:Class rdf:ID="Problem"/>
<owl:Class rdf:ID="AssessmentProject"/>
<owl:FunctionalProperty rdf:ID="ResearchQueston">
  <rdfs:domain rdf:resource="#Problem"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
</owl:FunctionalProperty>
<owl:FunctionalProperty rdf:ID="IntegrativeModeler">
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
  <rdfs:domain rdf:resource="#AssessmentProject"/>
</owl:FunctionalProperty>
<owl:FunctionalProperty rdf:ID="isProblemOf">
  <owl:inverseOf>
    <owl:InverseFunctionalProperty rdf:ID="hasProblem"/>
  </owl:inverseOf>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  <rdfs:domain rdf:resource="#Problem"/>
  <rdfs:range rdf:resource="#AssessmentProject"/>
</owl:FunctionalProperty>
```

Fig. 2. A snippet of an OWL-file, describing the concepts *Problem* and *AssessmentProject* and relationships *ResearchQuestion*, *IntegrativeModeller* and *isProblemOf* from Fig. 1. In an OWL-file, the ontology is stored in computer understandable format.

identified in the research consortium. In the design phase, agreement on the content of the common ontology is reached through a collaborative process. The common ontology is confirmed by the responsible researchers in the research consortium during the approval phase, while the communication of the common ontology to the whole research consortium occurs in the dissemination phase. In the remainder of this section, we focus on the design phase, because this is the most complex and challenging phase in building the common ontology.

In the design phase, the following steps should be undertaken: (i) iterative discussion with relevant researchers to define the content of the common ontology; (ii) edit the common ontology in a dedicated ontology editor and (iii) use the common ontology for software development of model, database and graphical user interface. The first step in developing a common ontology, is that a group of scientists must agree and adopt one tight, well-reasoned and shared conceptualization. The development of a common ontology by a group of researchers is a complex, challenging and time-consuming task (Musen, 1992; Gruber, 1993; Farquhar et al., 1995; Holsapple and Joshi, 2002). Tools are available that help in ontology development (Farquhar et al., 1995) and to store the ontology once it has been developed (e.g. Protégé OWL, Knublauch, 2005). To achieve ontological commitment, i.e. the agreement by multiple parties to adhere to a common ontology, when these parties do not have the same experiences and theories (Holsapple and Joshi, 2002), a collaborative approach is proposed to be used. A collaborative approach is based on 'development as a joint effort reflecting experiences and viewpoints of persons who intentionally cooperate to produce it' and it thus requires a consensus-building mechanism (Holsapple and Joshi, 2002).' A collaborative approach has two advantages. First, researchers from different disciplines are diverse in their contributions, which reduces the chance of blind spots and which has more chances of getting a wide acceptance (Holsapple and Joshi, 2002). Second, it can incorporate approaches other than the collaborative approach (e.g. inductive, inspirational, deductive approaches) as required for development of parts of the ontology. For example, we built parts of the assessment project ontology through the inductive approach, e.g. by observing and examining cases from the literature on scenarios in integrated assessments.

The second step in the design phase is annotating the ontology in a computer understandable language by entering the ontology in a dedicated ontology editor (Knublauch, 2005). The third step is using the ontology for the development of databases, models and graphical user interfaces. The common ontology, which provides a conceptual layer independent of different programming paradigms, can be translated in source code for different programming paradigms (e.g. relational database, object-oriented programming). The *Se*mantic-*Ri*ch *D*evelopment *A*rchitecture (SeRiDA) (Athanasiadis et al., 2007) can derive from this common ontology an object model and relational database schema. An object model is a schema of objects, properties and methods used in object-oriented programming. The SeRiDA facilitates the usage of appropriate tools for the tasks: (i) ontologies are used for storing semantics and supporting logical operations by reasoners, (ii) the object model is used for programming applications, graphical user interfaces, models and structuring the input to the models and (iii) the relational database schema is used for the persistent storage of data on assessment projects, scenarios, model inputs and results (Athanasiadis et al., 2007).

2.3. Case study: policy assessment for sustainable development

The SEAMLESS consortium develops a computerized and integrated framework (SEAMLESS-IF) to assess the impacts on environmental, social and economic sustainability of a wide range of policies and technological improvements across a number of scales (Van Ittersum et al., 2008). In SEAMLESS-IF different types of models and indicators are linked into model chains, where each model uses the outputs of another model as its inputs and ultimately indicators are calculated. With respect to the models (Fig. 3), macro-level economic partial or general equilibrium models (Britz et al., 2007) are linked to micro-level farm optimization models (Louhichi et al., 2009) and field crop growth models (Donatelli et al., 2009), using micro–macro upscaling methods (Pérez Domínguez et al., in press). These models provide, through their outputs, the basis for the calculation of indicators of interest to the user. Each of these models is derived from different disciplines, operates on different time and spatial scales, is programmed in different programming languages and has a different implementation of scenarios.

Within SEAMLESS, modelling and stakeholder involvement are considered equally important in the assessment procedure proposed by SEAMLESS-IF. For applying SEAMLESS-IF, we foresee an integrative modeller working together with a policy expert (Van Ittersum et al., 2008). Accordingly SEAMLESS-IF must be designed to facilitate such a participatory approach (Ewert et al., in press; Thérond et al., in press). Potential users have a different understanding of scenarios than the modellers and they should not be confronted with the different implementations of scenarios in the models.

An assessment project ontology is thus required within SEAMLESS to unify the different implementations of scenarios in the different models across the different scales, indicators, programming languages and assessment problems. The assessment project ontology is a common ontology for definition of assessment projects and scenarios and it acts on the interfaces between modellers and other scientists and between scientist and users after the development of the SEAMLESS-IF (Fig. 4).

In our case study of the SEAMLESS consortium, one example of an application of the common assessment project ontology is presented. The example refers to an integrated assessment project for the region Midi-Pyrénées in the South of France, concerning the impacts of the 2003 reform of the Common Agricultural Policy (CAP; EC, 2003) as requested by two members of a regional government agency. The CAP 2003 reform involves major changes in the subsidies that farmers receive for crops and animals (EC, 2003). The assessment must also incorporate the impact of CAP 2003 reform on conservation agriculture in the Midi-Pyrénées region.

3. Results

3.1. Collaborative approach

The collaborative approach consisted of set-up, design, approval and dissemination phases. In the set-up phase, the need for a project ontology was identified by scientists responsible for integration in the research consortium. The method to make the project ontology was proposed and agreed, after which the design phase started. The method is to develop one shared document in Microsoft Word on the meaning of scenario and assessment projects between a group of seventeen researchers from different disciplines working in different parts of the SEAMLESS consortium.

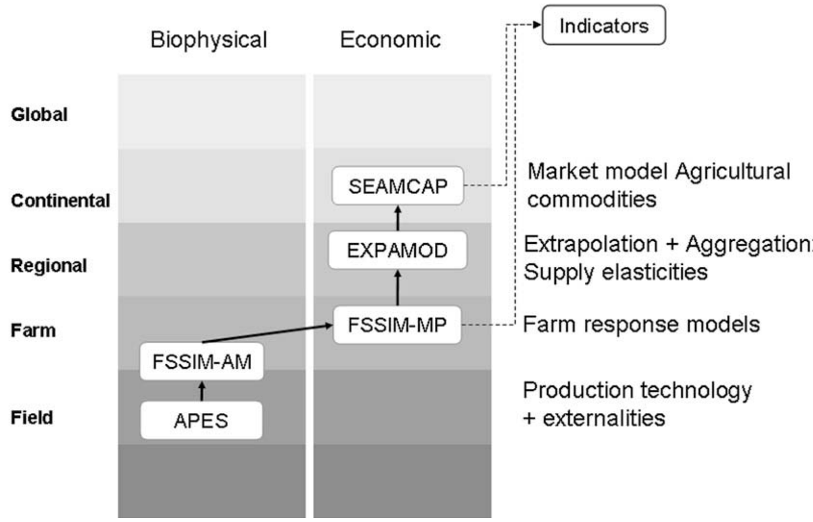

Fig. 3. Backbone model chain of SEAMLESS-IF for field, farm and market level analysis, from the bottom to the top of the figure, respectively.

In the design phase, ten iterations of the document were used and after each iteration an ontology constructed in Protégé OWL (Knublauch, 2005) was adjusted to the outcomes of each iteration. Two knowledge engineers acted as impartial facilitators, who proactively identified and discussed open issues to find agreement, without imposing own opinions about the content of the common ontology. They also edited the common ontology in an ontology editor. With each iteration, more scientists were involved starting from four for this first iteration up to seventeen for the tenth iteration (Fig. 5). Most scientists offered voluntarily to contribute to the document, as they realised the need for the document and were committed to the research consortium. Three scientists were included through invitations to contribute to the document, because of their crucial role in the research consortium and a balanced representation of the different research domains and roles in the consortium.

At the start of the document a clear and precise description of the aim and requested actions of the participants were provided, which was needed to avoid confusion. Due to the choice for a document, the descriptions of concepts and relationships in the document had to be such that the descriptions are not open to multiple interpretations. Formulations like ‘concept has one and only instance of another concept’ and ‘concept has one or more instances of other concepts’ were used for relationships and ‘concept is …’ or ‘concept is defined as…’ for definitions. In case of conflicts on the meaning of concepts or relationships, the two impartial knowledge engineers could mediate to build consensus. The consensus building usually occurred through asking questions to the domain scientists to further explain their ideas on the meaning of concepts and relationships. By asking questions new insights were obtained and the project ontology developed into a more advanced state. In some cases, meetings were organised, in which the domain scientists discussed unclear parts of the project ontology. During these discussions, the knowledge engineers made proposals on possible ontology structures until an ontology was accepted by all present.

In the approval phase after the tenth iteration, both the document and the ontology were ‘closed’ after the approval by the core group of researchers. At the tenth iteration, a set of actions was formulated to elaborate specific parts of the project and scenario definition. An example of an action was to investigate the relationship between scale and scenarios. Also, a set of four fictitious

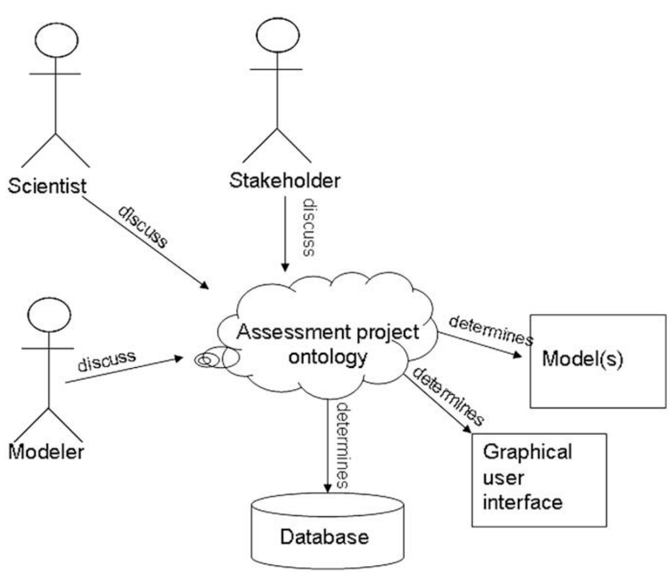

Fig. 4. Role of an assessment project ontology in an integrated assessment modelling project.

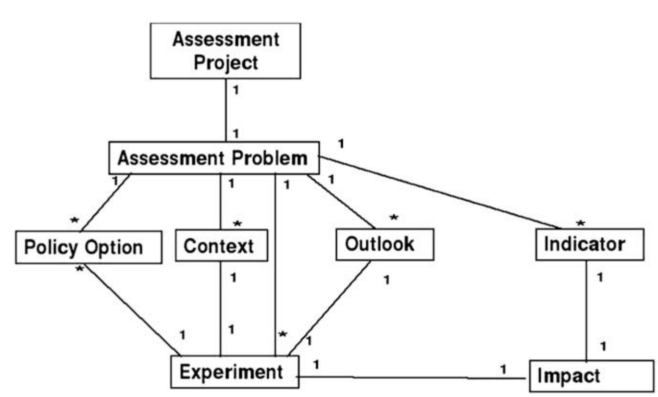

Fig. 5. A simplified data model of the project ontology with annotations between the concepts, indicating whether it is a ‘One-to-One’ relationship (1—1; one project is only related to one assessment problem and vice versa) or a ‘One-to-Many’ relationship (1—*; one experiment can have one or more policy options).

sample assessment projects was formulated during the iterations as a testing exercise of the ontology developed so far. One of these examples is presented below (Section 3.2.7).

In the subsequent dissemination phase, a group of seventeen scientists with high commitment to the assessment project ontology were available that consequently helped to further explain and establish the ontology with the scientists in the consortium. Interestingly, the scientists not involved in the process did not indicate any need to re-discuss the project ontology. These scientists were mainly interested in how their own research fitted to the developed ontology. Eventually, the ontology has been evaluated and accepted within the consortium. The wider evaluation of the common ontology is facilitated by making it open to scientists outside the consortium (see Section 4.2).

These four phases of set-up, design, approval and dissemination required about one and half year. The set-up and approval phases were both relatively short, e.g. a month. The design phase required about six months, with the two knowledge engineers working for 50% of their time on the assessment project ontology and domain scientists spending about one day at each iteration. The total time investment in the design phase is estimated at one and half man-years for the seventeen scientists involved. The dissemination through presentations or meetings to the rest of the consortium took about a year till all researchers were accustomed with the assessment project ontology. The set-up phase was initiated at the end of the second year on a total of four years of the research consortium. Advantages of initiating it at that time in the research consortium were that scientists were familiar with each other and each other's work and that a group of committed scientists interested in such an exercise could easily be identified.

3.2. *Assessment project ontology*

The content of the assessment project ontology is further verbally described based on the document developed. An assessment project in SEAMLESS refers to the assessment of changes in policies or technological innovations on the sustainability of agricultural systems. An assessment project consists of one or several *experiments* that capture a specific perspective on the assessment problem. A project has one and only one assessment problem. *One* problem has the following properties: (i) one spatial and temporal scale, (ii) one or more contexts, (iii) one or more policy options, (iv) one or more outlooks, (v) one or more experiments and finally, (vi) one or more indicators (Figs. 5 and 6).

3.2.1. *Scale*

Scale refers to the physical dimensions (most commonly space and time) of observed entities and phenomena (meaning that dimensions and units of measurement can be assigned). Each scale has two relevant attributes: the extent and the resolution. The extent defines the boundaries, the area or the magnitudes, for example from year for a temporal scale or continent for a spatial scale. Resolution refers to the finest detail that is distinguishable, for example a day for a temporal scale or member state for a spatial scale. Based on the models available in an integrated assessment project, a limited set of assessment scales is feasible. An example of possible assessment scales based on the SEAMLESS project is given in Table 1.

3.2.2. *Context*

Each experiment within a problem will be based on *one* context that can be different from those of other experiment(s). The context describes the delineation of the object of interest. The delineation determines what is inside and what is outside to the system modelled and defines the range of options or possibilities within which changes due to policy options and outlooks can occur. The properties of the context describe the input parameters of the simulation and combinatorial models. These models require assumptions to define and simulate options or possibilities used by other models to assess the consequences of a policy change or innovation. The context must contain assumptions on what is technologically possible in the future, for example will genetically modified cultivars become available at a large scale? Also, the context makes the abstract temporal and spatial scales (Section 3.2.1) concrete by specifying the temporal and spatial delineation. For example, for an assessment problem on the continental scale, the context specifies that the member states of the European Union in 2008 are of interest.

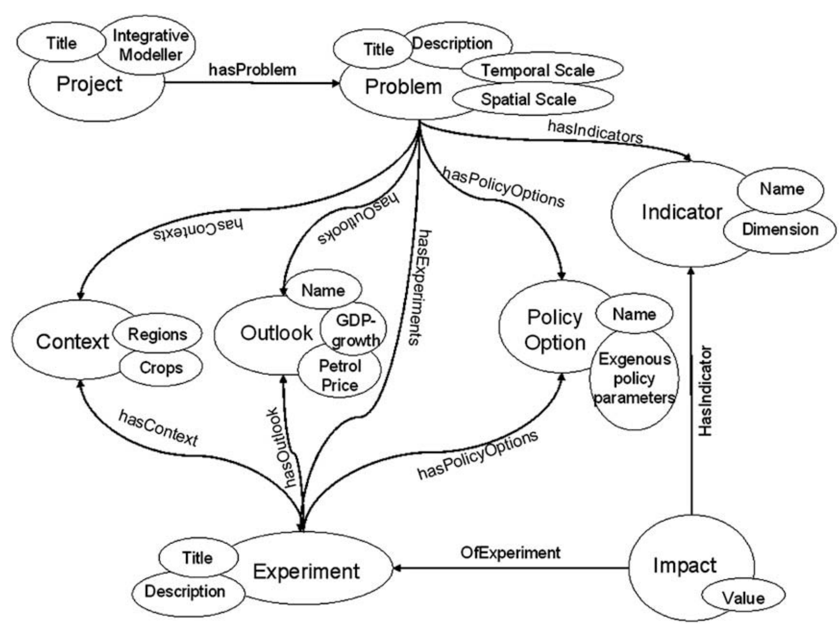

Fig. 6. Schematic overview of the assessment project ontology.

Table 1
Feasible scales of the assessment problem and models that can address a problem at that specific scale.

Extent	Resolution	Models
Continental	Agri-environmental zone	APES
Continental	Farm type	CAPRI–FSSIM-AM/MP
Continental	Region	CAPRI
Region	Agri-environmental zone	FSSIM–APES
Farm type	Agri-environmental zone	FSSIM–APES

3.2.3. Policy option

Each experiment within a project assesses the effects of one or a combination of several policy options. One policy option refers to one or more policy measures as part of it. Each policy option has a set of policy parameters within a given timeframe or for a given time series, that are not modified by any of the models in the assessment while running. An example of a policy option is the introduction of decoupled payments in the EU as part of the Common Agricultural Policy (EC, 2000). This policy option consists of two policy measures, which are the introduction of direct income-support and cut of area- or head-based premiums. These policy measures are quantified by the reference yield for a region to calculate the income-support level and the premium levels, which are cut.

3.2.4. Outlook on the future

An assessment problem can have one or more outlooks on the future. Outlook on the future describes trends and trend deviations foreseen to occur in society that might affect the implementation of policy options within a given context, but which are not modelled endogenously. Examples of outlook parameters of relevance to SEAMLESS are atmospheric CO_2-concentration, shifts in demands for agricultural products and energy prices. Outlooks are usually highly contestable images of what might happen in the future, and therefore it is recommendable to assess a problem under contrasting alternative outlooks, e.g. an economically oriented vs. an environmentally oriented outlook, a globalization vs. a regionalization outlook, a high-economic growth vs. a low-economic growth outlook. Sometimes these outlooks are based on discussions between a large group of researchers and stakeholders, for instance the IPCC Special Report on Emission Scenarios (SRES; IPCC, 2000).

3.2.5. Experiments

One assessment problem has at least two or more experiments. One experiment represents the assessment of one or a combination of several policy options in a given context and outlook on the future, which translates into *one* run of the models within SEAMLESS-IF and calculates values for a set of *indicators*. One experiment describes the reference situation, i.e. the baseline experiment (Alcamo, 2001). This baseline experiment consists of a policy option describing the policy instruments that are already phased in, or have been agreed upon, an outlook describing the projection of current trends and a context describing the current situation. The definition of one or more experiments assures that a with/without or before/after analysis of changes can be made. The experiments define the changes as compared to the baseline experiment, by capturing the changes in policy options, context, and outlook, either as changes in isolation (only one policy option/outlook/context-change) or simultaneously (more than one policy option/outlook/context-change). The maximum number of experiments is the full factorial combination of contexts, outlooks and policy options, although some combinations of contexts, outlooks and policy options may not be sensible and useful to assess.

3.2.6. Indicators

Each assessment problem is associated with a set of *indicators* that are of interest for the policy expert. Indicators synthesize relevant data and model outputs and indicate the change or define the status of something (Gallopin, 1997). A value for each indicator is calculated with a model run for an experiment. The indicators must be the same among experiments in one assessment problem allowing comparison of indicator values among experiments. *Impacts* are the changes in indicator value for one experiment due to changes in policy options, context and outlook as compared to the baseline experiment.

3.2.7. Example of regional assessment project in Midi-Pyrénées

The example introduced in Section 2.3 refers to an integrated assessment project for Midi-Pyrénées of the 2003 reform of the Common Agricultural Policy (CAP) and impacts on conservation agriculture. The spatial scale for this example has the extent of a *region* and the resolution of a *farm type*, as the example focuses on one region and on the impacts on specific groups of farms. The temporal scale has an extent of the period from 2003 to 2013 with a resolution of a year. The year 2003 is used for calibrating the models. The experimental set-up of the assessment problem with descriptions of experiments, outlooks, policy options and context can be found in Table 2. Relevant indicators for this assessment problem are the regional cropping pattern, the farmers' income, the amounts of subsidies, the % of no-ploughing tillage, the area for the intercrops mustard and clover and the level of erosion.

3.3. Ontology use for software development

The assessment project ontology is shown in diagrams, i.e. one data model (Fig. 5) and one ontology-schema (Fig. 6). The data model can only be translated into a database schema, while the ontology-schema can be translated both into a database schema and a set of classes for object-oriented programming through SeRiDA (Section 2.2). The assessment project ontology was used to generate a set of tables to store the project information in a relational database and a set of JavaBeans for communication between graphical user interface, models and database (Figs. 5 and 6). The JavaBeans are used to deliver parameters described in the ontology as inputs to the models. The assessment project ontology has impacted the design and set-up of the Graphical User Interface (GUI) of SEAMLESS-IF, as can be seen in Fig. 7. In Fig. 7 the part of the GUI is shown, where the problem is defined, by providing a description and selecting the temporal and spatial scale of the assessment problem. Through the

Table 2
Experiments designed in the assessment project for Midi-Pyrénées.

Experiments	Policy option	Outlook	Context
1. Baseline	Only current policies apart from CAP 2003 reform	Business as usual	No conservation agriculture
2. CAP 2003 reform	CAP 2003 reform	Economically oriented	No conservation agriculture
3. No support	CAP 2003 reform	Environmentally oriented	Conservation agriculture
4. Conservation oriented in regional world	CAP 2003 reform and subsidies for conservation agriculture	Environmentally oriented	Conservation agriculture
5. Conservation oriented in a global world	CAP 2003 reform and subsidies for conservation agriculture	Economically oriented	Conservation agriculture

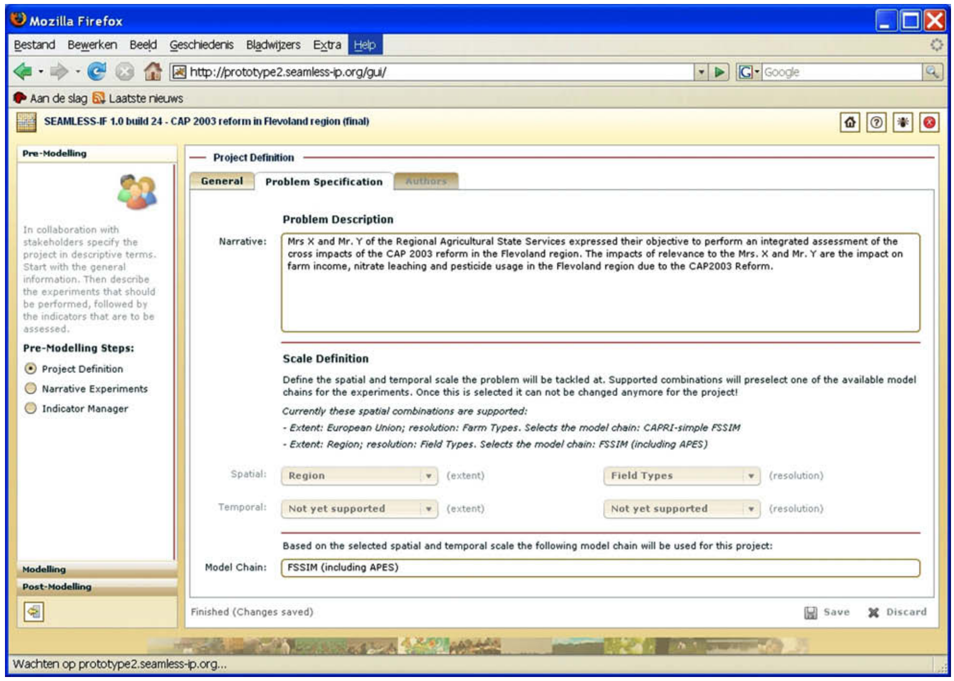

Fig. 7. Screenshot of the GUI displaying an assessment problem.

specification of the scales, the model chain of relevance is selected by the GUI and displayed. The GUI through the assessment project ontology enforces the explicit definition of the link between an assessment problem, a model chain and a spatial scale. Thereby the assumptions required to link an assessment problem, a model chain and a spatial scale become transparent.

4. Discussion

4.1. Scenario and its meaning

In our assessment project ontology as presented in Section 3, we have no explicit concept *scenario*. In the iterative process of building the common ontology, we experienced that scenario had different meanings for different scientists. During the process, some scientists thought of scenarios as experiments, so a perspective of future changes in parameters of policy options, outlooks and context, and thereby determining the input parameters for the models. Other scientists thought of scenarios as a set of impacts in the sense of indicator values that change depending on policies, outlooks and contexts. Economic modellers limited their definition of scenario to policy options, while biophysical modellers were more inclined to think of scenario as outlook. In the approval phase, the multiple meanings of scenario were demonstrated to all participants involved in the collaborative approach. The core group of scientists approving the proposed project ontology decided on a suitable definition of the word *scenario* for the research consortium, i.e. a scenario represents the changes or driving forces in policy options, outlooks and contexts in an experiment compared to the baseline experiment (Thérond et al., in press). Through the collaborative approach the multiple meanings of scenarios became managed and explicit decisions were taken, which increased transparency and clarity for scientist participating in the research consortium.

The concept *scenario* is further detailed through the assessment project ontology to cover a range of models and disciplinary understanding of what a scenario is. In the proposed assessment project ontology other concepts instead of scenario were chosen that could be defined unambiguously without multiple historical connotations, and agreed upon to avoid risk of confusion. Through the flexibility offered by concepts like context, policy option, outlook, experiment and assessment problem, the project ontology is able to cover all the different meanings which the concept *scenario* can have, and offers an opportunity to comprehensively describe an integrated assessment problem. Scenario definition as held by other stakeholders outside the science-community (e.g. policy makers) is not included yet in our assessment project ontology.

The different definitions and classifications of scenarios from literature as described in Section 1 were not readily usable as content in the assessment project ontology. We consider the assessment project ontology as a definition of scenario for multi-disciplinary and multi-scale research consortia in integrated assessment. Subsequent research should investigate, if it can become a standard for definition of scenarios and assessment projects across research consortia. The assessment project ontology in Section 3.2 presents a first simple formulation, that can be extended and detailed in further research. The simple formulation in Section 3.2 indicates that advanced and complex definitions and classifications from the literature are obsolete and not targeted.

4.2. Project ontology and models

The selection and configuration of models is not explicitly mentioned in the project ontology and the fictitious sample project as presented in Section 3, although a link exists between the properties of the context, outlook and policy option and input parameters for the models. As mentioned by Parker et al. (2002), scale is recognised as an important concept in integrated assessments and in our project ontology it is as a central node that determines (i) the models/model chains that should be run, (ii) the parameters or properties that should get a value with respect to outlook, context and policy option (Table 3), (iii) the indicators which can be selected and (iv) the results to be presented. In an integrated assessment we must make a distinction between the scales of the assessment problem and the scale(s) of the models. The scale of the assessment

Table 3
The relevance of properties of policy option, context and outlook for different types of models.

Models	Policy option	Outlook	Context
Crop growth simulation model	–	++	+++
Farm model	+++	++	+++
Market model	+++	++	+
General equilibrium model	+++	++	+++

– = No properties for this model.
+ = Limited number of properties.
++ = Average number of properties.
+++ = Many properties.

problem refers to the research question, properties of policy option, properties of context, properties of outlook and indicators. The scale(s) of a model is defined by the modeller and refers to the scale(s) at which relationships are modelled and outputs are simulated that are used at the scale of assessment.

Each assessment problem is linked to one spatial and one temporal scale, although this does not mean that multi-scale assessments are not possible. A multi-scale sustainability theme such as climate change or CAP 2003 reform has to be subdivided in several assessment problems, each on their own scale with relevant assessment question, indicators, model chain and properties of outlook, policy option and context. For example, in assessing the impact of climate change on agriculture, one feasible assessment problem is to study the impact of climate change on farmer income and environmental farm performance in a region, while another feasible assessment problem is the impact of climate change on farm production and trade in agricultural commodities in the European Union. Both assessment problems require different models at several spatial and temporal scales (Table 1), leading to two multi-scale assessments in terms of models and indicator values. Indicator values can be calculated at the scale of the assessment problem and finer scales, at which indicators can reasonably be calculated from available model outputs.

The properties of context, policy option and outlook are the input parameters to the models. One property can be an input parameter to more than one model. For example, a quota policy is defined by a value of the quota and a product to which the quota is applied for each farm type. This quota policy can be used both by a market-scale model and a farm-scale model. By specifying properties of policy option, context and outlook a library of possible model input parameters is created that can be used by different models. Hereby we decouple the description of an assessment project through relevant parameters from the use and implementation of these parameters by the models. This decoupling shifts the focus from the technical capabilities of the models to the assumptions made while defining values for the different model input parameters and defining the experiments (Rotmans, 1998; Greeuw et al., 2000). The use of experiments in defining projects also helps to make assumptions explicit, because these experiments capture the changes between a baseline experiment and the other experiments. By considering explicitly the differences between experiments, the changes in indicator values can be analysed. If many differences between two experiments occur, then it is more difficult to interpret the changes in indicator values. Designing sensible and useful experiments is therefore a challenging task.

By decoupling our understanding of scenarios and projects as captured by the assessment project ontology from the model input parameters, the assessment project ontology can be reused for other integrated assessment modelling research that deals with policy assessment and sustainable development and thus is a separate part of knowledge produced by a group of scientists as foreseen in the vision of the semantic web (Berners Lee et al., 2006). The project ontology is available on http://delivered.seamless-ip.org:8060/browser/zul/main.zhtml.

4.3. Use of ontologies and ontology engineering

To build the assessment project ontology a collaborative approach was used that involved scientists with different disciplinary backgrounds. By using ontology engineering as our methodology, scientists participating in this collaborative process had to be precise in their meaning of concepts they proposed for the common ontology. As an ontology can only support concepts, relationships between concepts and restrictions on relationships or concepts, scientist could only discuss in these terms. In other words, three conditions have to be met for a concept to be included in a common ontology: (i) the concept has to be clearly defined; (ii) the concept has to be consistent and coherent with other concepts in the ontology, (iii) one or more scientists have to provide the 'burden of proof' to fulfil the previous conditions.

With ten iterations and seventeen participating scientists, the collaborative approach required a clear objective, two persons managing the process (by setting deadlines, determining the type of contributions and the required participants) and a set of actions for each iteration, which made it a time-consuming task. Up to five participants sent contributions and feedback to each iteration of the document, which then had to be evaluated on their merits and which had to be discussed in case of diverging opinions. Critical success factors in the collaborative approach were the commitment of participants to the process and the presence of one or more knowledge engineers.

Many suitable tools to edit ontologies (see Knublauch (2005) and GO-Consortium (2007)) exist and we used these to edit the project ontology once consensus was reached. In the collaborative approach to reach consensus, we used Microsoft Word-documents. Documents had two advantages compared to dedicated ontology editors. First, all participants in the collaborative process have Microsoft Word installed on their computer and are used to communicate with documents. Second, the agreed ontology in the ontology editor was shielded from participants, as it is only necessary that a knowledge engineer edits the ontology in a dedicated ontology editor. Through track-changes and comments in the document, multiple participants were able to simultaneously edit the common ontology and their individual contributions could be followed and synthesized to a joint understanding of the problem at hand. We did not invest in the development of a tool for collaborative ontology editing, as initially we did not know the requirements for such a tool and the way the participants would work in this process. Through our experience of building the project ontology in a shared document, we learned that a website for ontology editing as proposed by Farquhar et al. (1995) could be helpful. However, such a website for ontology editing, in which all participants can edit the ontology, is only useful if it registers the users and their activities, if it allows a knowledge engineer to finalise parts of the ontology and make them non-editable, if it has a very simple and intuitive user interface to propose concepts and relationships to other concepts and if it forces users to use specific formulations to define concepts and their relationships. Wiki-technology could provide a useful starting point for the development of such a website.

5. Conclusions

Although literature provides many advanced and complex definitions and classifications of scenarios, these definitions and classifications cannot be made operational for research consortia in IAM. Our common ontology on assessment projects and scenarios provides an operational and simple definition of scenarios and assessment projects. It improves the consistency, transparency and applicability range across disciplines of scenarios, as (i) a set of concepts is provided to describe different types of model input parameters, (ii) the focus is on assumptions made in defining these input parameters instead of on the models, GUIs or databases themselves and (iii) experiments are explicitly constructed capturing the different perspectives and assumptions on the future. The assessment project ontology can be reused by other Integrated Assessment and Modelling consortia that deal with policy assessment and sustainable development and could become a standard for the definition of scenarios and assessment projects in the future.

We recommend for any integrated assessment consortium to clarify with its participants the meaning of scenario, associated concepts or other concepts with vague and ambiguous meaning (e.g. driving forces, indicators). We achieved such a clarification by the use of a common ontology, which forces participants to be clear, precise and coherent in their description of concepts and relationships between concepts. The common ontology can be directly used for development of databases, models and graphical user interfaces. A collaborative approach for clarifying concepts in a multi-scale multi-disciplinary research consortium was developed, while building our common ontology. This collaborative approach can be reused to extend the assessment project ontology or to build a shared understanding in other IAM research consortia.

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