The use of ontologies in peer reviews of Integrated Assessment Models

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Abstract

Integrated assessment models are used to analyze global change issues and they allow a better understanding of our complex environment. It is crucial to be able to relate these models to their scientific basis, both for interpretation and validation purposes. Current model evaluation procedures focus on model behavior analysis; the conceptual knowledge and assumptions embedded in integrated assessment models are hardly tested. As such, current model evaluation procedures do not contribute to the understanding of the structure of the models and the selected mechanisms and assumptions. We submit that evaluation of the scientific basis of integrated assessment models should follow the standard procedures for evaluation of scientific theories, which implies that these models should be subjected to critical peer reviews. However, much knowledge is hidden in the source code and therefore not accessible to peers. In this paper we propose to use ontologies – explicit specifications of shared conceptual knowledge – to represent the knowledge encoded in integrated assessment models in a clear and transparent way. We show the proposed peer review evaluation procedure in a case study concerning a system-dynamics model on residential energy use in India. We found that the ontology helped peers to obtain more information on the model and to gain more insight in its structure. However, a better balance between different types of model documentation and explicit links between them are needed to improve the understanding by the peers. We believe that ontologies can be exploited further in a computational sense in order to achieve model transparency.

***Keywords*:** ontology; integrated assessment; model evaluation; conceptual model

1. Introduction

Global change issues are analyzed using integrated assessment models, numerical models that integrate multiple (natural and socio-economic) academic disciplines. Integrated assessment models are often used for forecasting and management purposes, but their main value is heuristic, i.e. they allow a better understanding of complex phenomena [Oreskes et al., 1994, Rykiel Jr, 1996, Rotmans and Dowlatabadi, 1998, Risbey et al., 1996]. To allow proper interpretation of such a model, understanding the scientific knowledge captured by it is crucial. Unfortunately this knowledge is often poorly accessible to the users of the model, as it is hidden in the code or presented indirectly in publications and reports. It is clear that lack of transparency can be detrimental for both policy makers and environmental scientists [Jakeman et al., 2006].

The need for validation of integrated assessment models is widely recognized. Integrated assessment models incorporate knowledge from a broad range of mono-disciplinary theories.
In developing these models, modelers make choices on which parts of these theories to include in their models, which conditions to assume and how to translate all of these in model source code [Jakeman et al., 2006]. It is therefore important to test the conceptual knowledge and assumptions that are embodied in these models in addition to behavioral validation [Nguyen et al., 2007a, Rotmans and Dowlatabadi, 1998, Parker et al., 2002, Jakeman et al., 2006]. The literature on model validation is abundant and a confusing variety exists of used terminologies and methodologies [Nguyen and de Kok, 2007b]. But as current model evaluation procedures focus on quantitative tests for operational validation [Nguyen et al., 2007a], the conceptual knowledge and assumptions in integrated assessment models are hardly tested [Refsgaard and Henriksen, 2004, Nguyen et al., 2007a, Oreskes et al., 1994, Rykiel Jr, 1996]. As such, current model evaluation procedures do not contribute to the understanding of the structure and mechanisms of the modeled systems nor do they make integrated assessment models more reliable.

We believe that the knowledge embedded in integrated assessment models must be tested according to the standard procedures for confirmation or falsification of scientific theories, which implies that it should be subjected to critical peer reviews [Refsgaard and Henriksen, 2004]. Furthermore we believe that integrated assessment models can not be evaluated based on their scientific publications alone. These publications describe the underlying theories of a model and do not consider the knowledge that is actually captured in the model. A large part of the conceptual knowledge and assumptions is hidden in the model source code and has not been made explicit in a way that it can be understood and used without the modeler's mediation [Villa et al., 2009]. It is important that the knowledge captured in these models is represented in a clear and transparent way so that peers are able to assess its quality and appropriateness.

In this paper we propose to use ontologies [Gruber 1993] – explicit specifications of shared conceptual knowledge – to represent the knowledge encoded in integrated assessment models in a clear and transparent way. Whereas traditionally the focus is on mathematical variables and equations, ontologies describe the concepts, their attributes and relations. The concepts represent the factors that have been taken into account in the model, thereby providing a link between the human understanding of the model context and the variables used in the source code. This is in the spirit of Villa et al. [2009], who argue for semantically aware environmental modeling by using an explicit and meaningful representation of scientific knowledge. In the present study we make a first step by employing the textual representation of an ontology as a means to complement traditional documentation of system-dynamics models. However, we believe that the formal character of ontologies can be exploited further in terms of computational support for enhanced model transparency. The constructed ontology provides an additional layer on top of an Integrated Assesment model.

In this paper, we assess the usefulness of such an ontological layer in a case study on one of the modules in the Residential Energy Model India (REMI), a system-dynamics model on energy use by Indian households. This paper is organized as follows. In the next section we explain how we constructed the ontology for our case study module. We also describe the experimental set up for testing the possible benefits of an ontology in a peer review. In Section 3 we present the results of the peer review experiment and in Section 4 we reflect on the process of constructing the ontology and its contribution to transparency of the module. We address our main findings in Section 5 and finally discuss novel scenarios for transparent modeling.

2. Materials and methods

2.1 Formalizing knowledge in ontologies

The knowledge in integrated assessment models is based on a conceptualization: an abstract and simplified representation of the real world. An ontology is an explicit formal specification of a conceptualization, which describes the entities in a knowledge domain and relations among them [Gruber 1993]. The development and use of ontologies originated from Artificial Intelligence but nowadays many disciplines use them to share and annotate information in their fields [Noy and McGuinness, 2001;Villa et al., 2009]. Besides sharing common understanding of domain knowledge, ontologies can be used to make domain assumptions explicit and to enable reuse and analysis of domain knowledge [Noy and McGuinness, 2001]. Ontologies are not unlike traditional (relational or object-oriented) data models and database schemas; however they are different in the sense that they are expressed in terms of a shared, system independent language. In this study we used the OWL (W3C Web Ontology Language) formalism to construct an ontology. As the OWL formalism can also be understood by computers, a future step could for example be to automatically check the consistency of the knowledge expressed in that ontology.

In an ontology the entities in a knowledge domain are called 'concepts'. A concept in the domain of our case study model is for example Household. The concept Household does not refer to any particular household, but to the type of households that can be found in India. The actual meaning of the concept is defined through its 'properties' and 'relations'. The concept Household is characterized by the fact that it has for instance properties stating the associated residential area and expenditure. The relationship between the concepts Household and Person is defined by the property 'has person'; every household consists of a number of persons, defined by the concept Person.

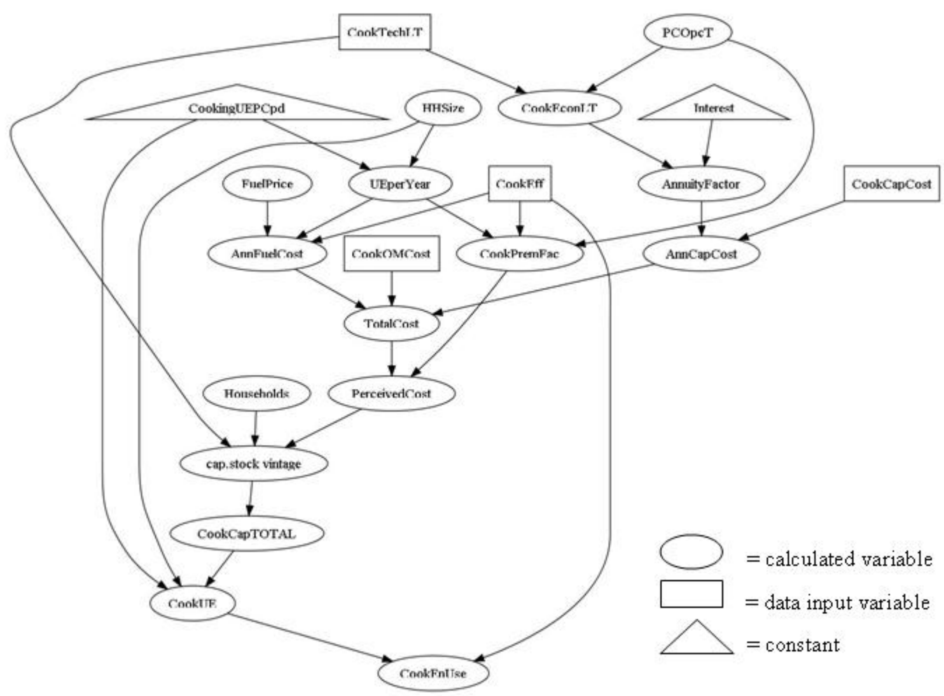

Figure 1: Simplified representation of the flow chart of the CookWater module of the Residential Energy Model India [Van Ruijven, 2008]. Variable names in the flow chart are similar to those used in the source code.

2.2 Constructing an ontology for the Residential Energy Model India

The Residential Energy Model India [Van Ruijven, 2008] is a system-dynamics model that determines the energy use by Indian households. The model specifically addresses the socio-economic factors influencing energy uses. It includes knowledge on consumer behavior, public health and sustainable development. In this study we focus on one specific module in REMI on energy use for cooking and water heating. The REMI model has been developed using the integrated software environment M [De Bruin et al, 1996]. The model source code resembles the syntax of mathematics common in writing, describing the causal relations between model variables through difference and differential equations. Besides the source code, the model documentation consisted of a thesis chapter, describing the underlying theory of the REMI model and a flow chart (figure 1) giving a visual representation of the causal relations between the model variables.

We studied the model documentation to gain insight in the aim, structure and main processes in the module. To construct the ontology for this model we extracted the scientific concepts and relations hidden in the source code. We used the model source code to list and define all variables present in the module and grouped them according to subject. In consultation with the modeler we then defined the main concepts in the module and represented all module variables as properties of these concepts (figure 2). We did not use the variable names as used in the code for these properties but chose clear names to represent their function. From the thesis chapter we assumed several relationships between the concepts in the module, but these were difficult to identify in the source code. In consultation with the modeler we defined these relationships in our ontology, representing them as relations between the concepts. Finally we constructed a glossary that provided definitions of the terms used in the ontology diagram and linked those terms to variables in the REMI module (table 1).

Table 1: Glossary (example part) of terms in the ontology diagram and associated variables in the CookWater module of Residential Energy Model India [Van Ruijven, 2008]

Term in Ontology	**Definition**	**Associated model variable**
Population group	Group within Indian population; there are 10 types of population groups according to different income level and residential area	…
has residential area	Area where people in a population group live in; can be either urban or rural	…
has expenditure	Expenditure level of a population group; can be either low, low-middle, middle, high-middle or high	…
has household	A population group consists of multiple households of type household	…
has nr of households	Number of households in a population group	…
has net yearly energy use for cooking + waterheating	Net yearly energy use of a population group for cooking and waterheating; per fueltype, in MJ	…

2.3 Application of the ontology in peer reviews

The aim of the constructed ontology was to give a clear and transparent representation of the knowledge captured in the REMI module, an intermediate between the source code and textual descriptions. We performed a peer review experiment as a proof of principle for ontological model transparency, but also to receive qualitative feedback on our approach. We organized two peer review sessions with comparable peer groups consisting of four scientific researchers employed at the Netherlands Environmental Assessment Agency representing different disciplines, viz., economics, sustainable development, energy and public health. In both groups the modeling experience of peers ranged from researchers with no modeling experience to researchers who were familiar with the programming environment that had been used for the development of REMI. In session 1 experts were given only standard model documentation, which existed out of the thesis chapter describing the model, the flow chart (figure 2) and the source code. In session 2 experts were given the same standard documentation, plus the ontology diagram and the accompanying glossary.

After a short introduction on the aim and context of the module, we asked the experts to determine if the module consisted of the right elements to achieve its goal, or that elements should be added or deleted. During the sessions, which lasted 90 minutes, the experts were allowed to discuss these issues. They were not allowed to ask questions to the modeler or to the workshop supervisor. We observed the behavior of the experts during the sessions and registered group discussions on a voice recorder. At the end of each session we evaluated our experiences with the experts and the modeler.

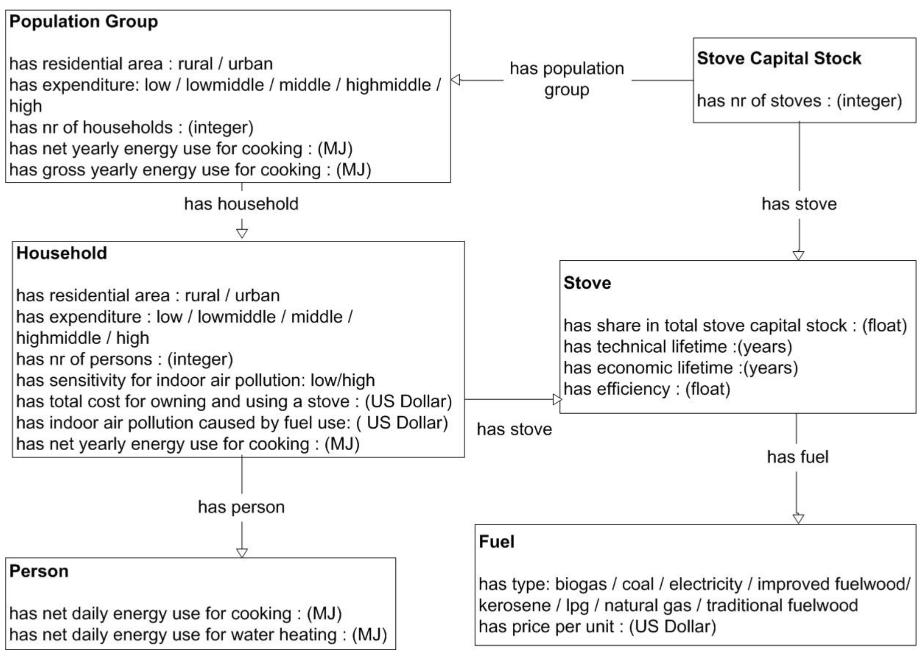

Figure 2: Ontology diagram (simplified version) of the CookWater module of Residential Energy Model India [Van Ruijven, 2008]

3. Results

The following observations were made in the two groups. In group 1, the experts had access to the thesis, the flow chart and the source code. We noted that the thesis was the most frequently used source of information. Experts in group 1 questioned certain statements in the thesis documentation and stated that some information was lacking or could not be found. They assumed, for example, that “family size” and “distinction between urban and rural population groups” were important factors influencing residential energy use, but in the thesis they could not find whether these factors were included in the model. The experts indicated that it was difficult to get an overview of all used factors in the model, and that it was therefore difficult to answer the evaluation question.

In the second group, all forms of documentation were frequently used: thesis, ontology diagram, glossary and source code. The experts also tended to start with the thesis as a source of explanation. In this group, the thesis documentation also appeared to lack certain information, but in about 50% of the cases the missing information was then retrieved from the ontology diagram and the glossary. Factors like "indoor air pollution" or "family size" were deemed to be important and could indeed be found in the ontology diagram. However, even with the ontology and the glossary given, the experts found it difficult to have a good overview of all factors used in the model, given the time available.

In both workshops experts showed a preference for the thesis as a source for model documentation. However, the thesis explains the theory behind the model, but not the knowledge as actually encoded in the model. Group 2 additionally used the ontology diagram and accompanying glossary, which are more true representations of the information included in the model. These documents helped the experts in group 2 to obtain information missing from the thesis chapter and to gain more insight in the structure of the model than group 1.

In both workshops we reflected on the experiment in a subsequent discussion with the modeler and the experts. All experts thought that 90 minutes was too short to get a good overview of the model. In group 1, experts found that they missed information as they did not have enough time to read the thesis documentation thoroughly. Experts in group 2 stated that they had too much information to choose from. The modeler observed that, in his opinion, the experts from both groups did not have a full overview of the main processes and assumptions in the module at the end of the sessions.

With regard to the provided model documentation, experts from group 1 indicated that they could not link terms in the thesis documentation to variables in the flow chart and source code as they all had different names. They also suggested that it would have been useful to have a schematic overview of the module that is less detailed and complicated than the flow chart (see Figure 2). Experts from group 2 found the ontology diagram and glossary useful, although they indicated that the definitions of the ontology terms in the glossary could have been stated more clearly.

4. Discussion

In our experiment the experts in both groups showed a preference for the thesis documentation as they assumed that the text in this document corresponded exactly to the information in the model. They also assumed that it was scientifically correct as it had been peer reviewed. Their confidence in the one-on-one correspondence of model and thesis was however too optimistic, since a thesis is not a living document and changes in the model do not lead to changes in the thesis.

The group discussion showed that the experts did not fully answer the evaluation question as they did not discuss the module at a suitable level of abstraction. As an explanation the experts mentioned lack of time, information overload and lack of recognizable connections between the different types of model documentation. As we aim for effective and efficient model evaluation procedures, it is not desirable to extend the duration of peer reviews. We believe that a more deliberate use of the different types of model documentation could enhance the experts' understanding of the module. Moreover, links between the different types of documentation should be made more explicit. Ideally, model documentation gives a transparent representation of the knowledge captured in a model. Ontologies are useful in this process as they are representations of the knowledge captured in models, thereby bridging the gap between source code read by computers and language read by humans. The ontology diagram as used in this experiment is a first step towards understanding a model in conceptual terms. We believe, however, that the use of ontologies to enhance model transparency is still in its early days.

The first step is to introduce ontologies as an additional conceptual layer of information for integrated assessment models. These systems-dynamics models are typically constructed around numerical variables that are related through mathematical relations representing causal dependency relations. However, a conceptual description explaining these concepts and relations is usually missing, even if careful model documentation is provided. An ontology provides a view that is orthogonal to the system dynamics view in the sense that it employs a linguistic rather than mathematical view. Our hypothesis is that this complementary (meta-level) perspective can contribute significantly to the much wanted model transparency in integrated assessment modeling.

Constructing an ontology for REMI was a time consuming activity for the knowledge modeler, as deducing concepts, properties and relationships from the list of module variables was not at all a trivial task. It turned out that the existing model documentation did not provide sufficient information to get a good overview of the structure and processes the module. In fact one could argue that good conceptual modeling practice [Refsgaard and Henriksen, 2004] requires proper data modeling already in the development phase. However, in practice this approach is not always followed due to time constraints and lack of modeling support [Jakeman et al., 2006]. Ontologies can help to fill this gap because they are formal representations that are amenable to computer processing. For example, model inconsistencies can be detected automatically. At present, no tools exists that assist systems-dynamics modelers in particular in building ontologies.

Another potential benefit of ontologies is that they are expressed in standardized languages. This allows world-wide exchange and reuse of (parts of) conceptual models through the web. In fact, ontologies have their highest impact on the world-wide web, turning it into a Semantic Web, or better the Web of Data. In the area of Integrated Assessment the quality and transparency of models would highly benefit from freely exchanged model data, concepts and mechanisms.

5. Conclusion and recommendations

The aim of our experiments was to assess the usefulness of ontologies as a link between the human understanding of an Integrated Assessment model in natural language and the knowledge captured in the source code of the model. In a peer reviewed model evaluation we compared the use of an ontology with the use standard model documentation only.

We observed that the ontology helped experts to obtain more information from the model and to gain more insight in the model structure. However, even with the ontology diagram, experts could not get a good overview of all used factors in the model and therefore had difficulties evaluating the model. We believe that a more deliberate use of the different sources and explicit links between different types of model documentation could enhance the experts' understanding of a model. Ontologies are useful in this process, bridging the gap between source code read by computers and language read by humans. As stated above, they can enable a world-wide discussion between model experts, while staying close to the actual encoded models.

The ontology diagram as used in this study is a first step towards explaining a model in conceptual terms, complementary to the system-dynamics perspective. As a next step following our review experiments we plan to use the computational capabilities of ontologies by giving experts access to the model documentation via a computer application. The core this application is the ontology, which provides an formal description of the concepts, attributes and the relations between the concepts in the model. By hovering over or clicking on concepts in the ontology diagram, the experts are guided through corresponding elements of the model and model documentation. We expect that by giving the ontology a central position in the model evaluation session, experts are more likely to understand the model on a conceptual level.

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