Environmental Modelling & Software 55 (2014) 235–241

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Environmental impact assessment based on dynamic fuzzy simulation

Ralf Wieland [a,*], Carsten Gutzler [b]

[a] Leibniz-Centre for Agricultural Landscape Research, Institute of Landscape Systems Analysis, Eberswalder Str. 84, 15374 Muencheberg, Germany
[b] Leibniz-Centre for Agricultural Landscape Research, Directorate, Eberswalder Str. 84, 15374 Muencheberg, Germany

ARTICLE INFO

Article history:
Received 16 August 2013
Received in revised form
15 January 2014
Accepted 1 February 2014
Available online 22 February 2014

Keywords:
Quick scan
Environmental impact assessment
Fuzzy modeling
Dynamic fuzzy simulation

ABSTRACT

A new “quick scan” method for an expert-/stakeholder-based impact assessment approach is introduced. This approach aims to reduce the complexity of models, to simulate and visualize the system dynamics and to provide a basis for guided discussion with stakeholders. The approach is based on dynamic fuzzy models that can be understood easily and developed by experts and understood and adapted by stakeholders (“white box models”). This open modeling process also forms the basis of the credibility of the simulation results. The quick scan approach is supported by an interactive simulation tool that includes optimization and uncertainty analysis as open source software.

Software availability

Name of software: Fuzzy_SIMU
Developer: Ralf Wieland, Karin Groth
License: GPL v3
Year first available: 2013
Contact: rwieland@zalf.de
Hardware requirements: Intel/AMD PC 4 GB RAM
Software requirements: Linux® or Microsoft Windows® using Oracle virtualbox
Availability: http://www.zalf.de/en/forschung/institute/lsa/forschung/methodik/samt/Pages/default.aspx as SAMT3_4.ova (virtual appliance)

1. Introduction

Policies in the European Union are based on the concept of sustainable development. One of the tools to ensure sustainable development is the mandatory assessment of the probable consequences of all new policies before legislation is passed. In 2005, the European Commission published guidelines on how to conduct such integrated impact assessments; these guidelines were updated in 2006 and 2009 (CEC, 2009). Similar assessments for national legislation are being discussed or have already been implemented in some EU Member States, such as the UK.

One of the challenges involved in this process is to consider and equally weight all of the relevant economic, ecological and social effects of new policies (Hertin et al., 2009). Science can help support the impact assessment process by developing methods and tools (Thiel, 2009). In order to be applicable in a policy context, however, scientific methods must meet credibility, relevancy and legitimacy criteria (Cash et al., 2003). Complex quantitative models are usually considered by non-experts to be “black boxes”, damaging the credibility of their results (Hutchinson and Gigerenzer, 2005; Goldstein and Gigerenzer, 2009). In addition, the model calibration and specification process for a given problem is often so time-consuming that the results are no longer relevant for political processes, which require fast answers.

Expert- and stakeholder-based approaches (Voinov and Bousquet, 2010) for generating information are much faster, and are easy to combine with public participation and consultation. Such approaches make use of existing knowledge, and may enhance political relevance by including relevant actors in the assessment process. However, they may lack credibility because the results cannot be repeated easily, they depend heavily on the composition of the groups consulted, and usually fail to give a measure of the uncertainties surrounding the results. New methods endeavor to combine model- and expert-/stakeholder-driven approaches: quick evaluations by experts and stakeholders generate a preliminary assessment in which the available information is compiled and critical issues are identified. These issues

* Corresponding author.
E-mail address: rwieland@zalf.de (R. Wieland).

http://dx.doi.org/10.1016/j.envsoft.2014.02.001
1364-8152/

are then analyzed in detail by applying quantitative models. This approach was recently adopted by the European Environment Agency (Verweij et al., 2012). In our paper, we present a new modeling approach that can support the integration of expert and stakeholder knowledge into the impact assessment process. Our approach enables the correlations of system variables on which experts base their judgment to be visualized and documented. It captures system dynamics, including feedback and trade-offs, and shows how state variables develop over prolonged periods of time. By using an optimization algorithm, preconditions for achieving the desired ecological, economic or social development can be calculated.

1.1. The aim of quick scan models

The question is: "How can informatics support the political debate and decision-finding?" There is a long tradition of creating simulation software to help us understand complex environmental systems. This development started with the world simulator (Meadows et al., 1974, 2006). Today, a climate simulator "C-ROADS" (Sterman et al., 2013) aims to enable us to understand the impact and reactions of the complex world climate system. What all these simulations have in common is that they help us to understand the system, rather than to calculate ideal development pathways. In other words, they can assist in a debate, but decisions must be taken by a community consisting of politicians, stakeholders and experts.

Another challenge in addition to complexity is accounting for system dynamics. Even simple dynamic problems cannot be solved without a simulation, or at least a calculation, as shown in (Wenkel et al., 2008). The use of simulation software is state of the art in engineering. In environmental science, too, the use of simulation is gaining in importance (Rizzo et al., 2006; Holst, 2013). In impact assessment, dynamic simulation is used to help us understand the dynamics of the real world.

Those involved in an expert- and stakeholder-based approach must understand the model, else the simulation results will not be considered credible. This can be achieved if the actual modeling approach becomes part of the discussion with stakeholders (Voinov and Bousquet, 2010; Michener et al., 2012). In our approach, we create "white box models" involving the implementation of expert knowledge. These models then become part of the dynamic simulation model describing the interaction and dynamics of the system. Experts are responsible for the scientific soundness of their models. The modeling structure, the system variables, the inputs and outputs, the parameters, the model compartments and interactions between compartments should be open to discussion. The defining of fuzzy rules and correlations between variables has the additional advantage of explaining and documenting expert's assumptions about their subject which form the basis of their judgment. It is important that stakeholders see that their concerns are addressed in the model, or at least that they know why their part is irrelevant for the simulation.

Another important point is that quick scan models must be ready for use as soon as a problem emerges. An impact assessment study by Gutzler et al. (2013) concerning the effects of agricultural development pathways in the Federal State of Brandenburg, Germany involving nine indicators from the social, economic and ecological dimension took about two years to complete, from start to finish. Such excessive time requirements make it difficult to support the political decision-making process. We therefore propose a method that can be implemented quickly, albeit at the cost of precision and being spatially explicit.

1.2. Key features of quick scan models

Developers of quick scan models must solve a number of problems.

Firstly, they have to reduce complexity according to "Occam's razor: simpler explanations are, other things being equal, generally better than more complex ones". The frequent combination of models, for example in multi-agent-based models such as Le et al. (2010), leads to more complex models and should be viewed with caution.

Secondly, they have to implement system dynamics. The use of conceptual models such as fuzzy cognitive maps often feature a poor implementation of dynamics (Carvalho, 2011; Kok, 2009). In addition to system dynamics, there is also dynamics in inputs to implement. The impact of climate change is one example.

Thirdly, they have to create models that can win stakeholders trust. The traditional scientific approach consisting of data collection, modeling and validation can only be used in part. There is often insufficient time for validation, even if such data is available. The best strategy that we can suggest is to:

open the modeling approach to include experts in the model refining process,

- open the system design to create reliable, coherent models,
- implement fast prototyping to support an interactive modeling development process.

2. Method

As mentioned above, it is important that models follow a "white box" approach, making them reliable and open. Fuzzy modeling guarantees that models can be understood and adapted by experts and stakeholders alike. It is important for experts to see how their knowledge is included in the models, and for them to be able to adapt them, if necessary. Stakeholders are more involved in defining parameters to control simulations. Stakeholders define starting values that best represent the desired scenario or current situation. After gaining an impression of the systems behavior, they define control variables, adapt the initial conditions, and so on, to achieve the desired development of the system. Ideally, the simulation responds like a computer game, that means it is interactive and the user gets a fast response.

2.1. Model description

In order to explain the use of dynamic fuzzy models in impact assessment, agricultural development scenarios for the German Federal State of Brandenburg were used as a test case. The same case had already been investigated by Gutzler et al. (2013). Brandenburg is a state that is traditionally strong in agricultural production, mainly cereals. Cultivation of silage maize for energy production has experienced an increase in recent years due to economic profitability, harboring ecological risks (e.g. greater erosion), social risks (e.g. negative impact on the beauty of the landscape) and economic risks (e.g. fewer tourists). We must point out that the model was created to demonstrate the power of the approach; it does not yet include stakeholder inputs.

In order to investigate whether a regions development is sustainable, the simulation must span one or more decades. In our approach, our choice of 25 years enables developments to be visualized, but avoids projections that go too far into the future, when current assumptions and correlations between variables may no longer be valid. State variables were chosen to represent the three dimensions of sustainability: the economic dimension (*Oec*), the social dimension (*Soc*) and the ecological dimension (*Eco*). The *Eco* is here connected to the agricultural production, the *Eco* reflects the bundle of efforts for environment protection and the *Soc* represents the balance between the need for environment protection (for water protection, water erosion protection, etc.) and the level of protection. These variables influence one another, and are additionally influenced by a number of indicator variables: per hectare yields (*YIELD*), prices for agricultural products (*P*), area under irrigation (*Irr*), landscape characteristic (*LC*), water protection (*Wat*), biodiversity (*Bio*) and erosion protection (*Ero*).

The parameters are:

- the price ($P = P_w + P_s - cost$), which is a sum of the world market price (P_w) and subsidies (P_s) minus production costs ($costs = const.$);
- the area of irrigation (Irr) as a percentage of the cropland;
- variables *Wat*, *Bio*, *Ero*, *LC*, which is the percentage of the area under investigation that (according to experts) is threatened by negative impacts and requires protection;
- agricultural yield (*YIELD*) is treated as a stochastic input estimated from past statistics (possibly plus an additional trend) (Mirschel et al., 2012), including the impact of the climate.