Jul 1st, 12:00 AM

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Sina Frank
Tuck-Fatt Siew
Petra Döll

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Düspohl, Meike; Frank, Sina; Siew, Tuck-Fatt; and Döll, Petra, "Transdisciplinary research for supporting environmental management" (2012). International Congress on Environmental Modelling and Software. 283.
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Transdisciplinary research for supporting environmental management

Meike Düspohl¹, Sina Frank¹, Tuck-Fatt Siew¹, Petra Döll¹
¹Institute of Physical Geography, Goethe University Frankfurt, Germany
duespohl@em.uni-frankfurt.de

Abstract: Generation and integration of different forms of disciplinary knowledge and knowledge outside of academia have become increasingly important in the effort of tackling real-world problems that are related to complex and uncertain human-environment systems. In recent years, transdisciplinary research has emerged as a collaborative and integrative approach for the co-generation of system knowledge, target knowledge, and transformation knowledge among scientists and stakeholders. In this paper, we present a methodology for participatory modelling processes that we apply in a transdisciplinary project for sustainable energy supply based on renewable energies in the county of Groß-Gerau in the German state of Hesse. The core of the transdisciplinary research project is a stakeholder dialogue including stakeholder interviews and a series of workshops. The participatory processes will be supported by actor-based modelling and Bayesian network modelling for joint knowledge generation and integration among scientific experts and institutional stakeholders. Actor-based modelling is a semi-quantitative method used for the analysis of problem perceptions that are depicted in perception graphs (PG). These perception graphs are analyzed with the software DANA (http://dana.actoranalysis.com) in order to identify sustainable development paths. On the other hand, probabilistic Bayesian Networks (BNs) can be used to model complex problem fields using quantitative data as well as qualitative expert judgments. In our study of the problem field, we aim at developing implementable management strategies, particularly by the generation of qualitative and quantitative scenarios.

Keywords: transdisciplinary research; participatory modelling; Bayesian Networks; actor modelling; actor-based modelling; participatory scenario development.

1 INTRODUCTION

Transdisciplinary research has emerged as an integrative approach that enables scientists and stakeholders to collaboratively tackle real-world problems (Thompson Klein et al. 2001, Hirsch Hadorn et al. 2006). The core of transdisciplinary research is generation and integration of knowledge inside and outside of academia through the participation of all relevant disciplinary scientists and stakeholders (Jahn 2008, Mobjörk 2010). In the context of environmental and natural resources management, transdisciplinary research processes were conducted for addressing issues which are related to complex and uncertain human-environment systems. These include water management (Cain et al. 2003), sustainable agriculture development (Vandermeulen and Huylenbroeck 2008), regional planning (Wiek and Walter, 2009) and conservation planning (Steventon 2008; Reyers et al. 2010). The number of publications on transdisciplinary research has increased five-fold in the past ten years (http://www.transdisciplinarity.ch/e/Bibliography/ [Accessed: 22.2.2012]). In transdisciplinary research, integration of stakeholders in the research process enhances shared understanding of the problems and mutual learning through joint knowledge generation. Consequently, transdisciplinary research provides the opportunity for social learning towards sustainability (Luks and Siebenhüner 2007).
Bergman et al. (2010) and Hinkel (2008) presented and discussed a number of concrete methods for doing transdisciplinary research. Hinkel (2008) distinguished between analytical and participatory methods and made clear that for “each new problem raised, the relevant processes need to be identified and the available models about them selected and configured appropriately” (Hinkel 2008: 6).

In this paper, we present a methodology for participatory modelling and scenario development that we apply in a transdisciplinary project for sustainable energy supply based on renewable energies in the county of Groß-Gerau in the German state of Hesse. Our goal is to investigate methods that are suitable for supporting transdisciplinary knowledge integration. In the next section, the concept of transdisciplinary research is briefly introduced. We then present participatory modelling and scenario development methods that are used to support the transdisciplinary process. Subsequently, the implementation of transdisciplinary research for supporting the development of sustainable management strategies in Germany is described. This is followed by discussion of the first results and conclusions.

2 TRANSDISCIPLINARY RESEARCH

Transdisciplinary research may be done in form of a recursive process, to support adaptive management that includes joint knowledge generation and integration among scientists and stakeholders (Siew and Döll 2012). As depicted in Fig. 1, each cycle of transdisciplinary process consists of five steps, comparable to steps in an iterative policy cycle (Pahl-Wostl 2008: 3), including stakeholder and scientist involvement:

1. Problem (re)definition (framing of the problem taking into account different perceptions of scientists and stakeholders as well as the interests and goals of relevant stakeholders).

2. Problem analysis and strategy development

3. Implementation

4. Monitoring

5. Evaluation

Figure 1. Transdisciplinary research as a recursive process to support adaptive management, with joint knowledge generation by stakeholders and scientists (Siew and Döll 2012).
Step (1), (2) and (5) are executed jointly by stakeholders and scientists. In each of these steps, system knowledge, target knowledge and transformation knowledge are co-generated (The terms system knowledge, target knowledge and transformation knowledge were introduced by CASS/Proclim (1997)). System knowledge provides understanding of the interactions of human-environment systems; target knowledge relates problem perceptions, goals and interests of stakeholders; transformation knowledge guides the identification of possible pathways that can lead to goal achievement.

In transdisciplinary research, stakeholders can be involved through consultation or active participation (Mobjörk 2010). In our studies, we focus on the latter due to its higher potential for broad knowledge integration. Previous studies showed that participatory processes lead to a higher quality of decision-making (Sultana and Abeyasekera 2007). In the next section, we present selected transdisciplinary research methods that can be applied in steps 1, 2 and 5.

3 Transdisciplinary Methods

Actor-based and Bayesian Network modelling are done by scientists (“analysts”), and the modelling process needs to be carefully embedded in a participatory process in order to serve as transdisciplinary research methods.

3.1 Actor-based modelling

Semi-quantitative actor-based modelling is a modelling method that focuses on analyzing the specific problem perception of each stakeholder (Döll and Döll 2008). The premise is that the actions of stakeholders are guided by their own subjective perception of a problem. Actor-based modelling aims at identifying realizable strategies by modelling actor perceptions, actions and the resulting changes of key factors.

Actor modelling is a software-supported formalized actor analysis, which focuses on modelling the different problem perceptions of institutional stakeholders (not individuals). The software used for actor modelling and actor-based modelling is DANA (http://dana.actoranalysis.com/; Bots 2007). Based on interviews, problem perspectives of the stakeholders are depicted in semi-quantitative perception graphs (PGs). These perception graphs are directed acyclic graphs. In each PG, the causal relationships between goals of the stakeholder, possible actions of the stakeholder itself and other stakeholders, expectations and relevant factors are quantified on a scale of 7 (1 star to 7 stars). On the basis of this quantification, optimal actions from the perspective of the individual stakeholder can be computed.

The perception graph of each stakeholder can be combined semi-automatically to generate an overall graph (analyst’s PG). In the analyst’s PG, all stakeholder perspectives are integrated and combinations of optimal action can be modelled. Through exchange and discussion of PGs, actor modelling enhances mutual understanding of different perspectives among stakeholders. Discussing the structure of the Analyst’s PG increases the system knowledge of stakeholders and scientists, while the simulations carried out through actor-based modelling provide target and transformation knowledge with regard to possible pathways to achieve goals.

Actor-based modelling includes actor modelling as the first step. In the next step, actions of stakeholders are simulated, i.e. the actions that relevant stakeholders will take under specific scenario conditions, taking into account the actions of other stakeholders. In the third step, the so-called modelling of factors, the changes in relevant factors (physical variables) resulting from these actions are estimated in a semi-quantitative manner (Döll and Döll 2008). There is no feedback from the physical variable to the actions. Actor modelling was used in the problem
field of pharmaceuticals in drinking water (Titz and Döll 2009), while actor-based modelling was applied in the problem field of mobile organic substances in surface waters (Döll and Döll 2008).

3.2 Bayesian network modelling

Bayesian networks (BNs), also known as Bayesian belief networks, have gained popularity in environmental modelling and management during the past decade. Recent applications of BNs range from water management (Castelletti and Soncini-Sessa 2007, Carmona et al. 2011), ecological management (Borsuk et al. 2006, Howes et al. 2010) and land use management (Aalders 2008) to management in the energy sector (Cinar and Kayakutlu 2010, Blonbou 2011).

The growing interest in BNs is linked to the recognition that uncertainty of knowledge and participation of stakeholders play a key role in modelling human-environment-interactions and in integrated environmental management (Castelletti and Soncini-Sessa 2007). The probabilistic presentation of knowledge in Bayesian networks emphasizes the uncertainty of knowledge and prevents overconfidence in the response of management interventions (Uusitalo 2007). Like the perception graphs in actor-based modelling, BNs are directed acyclic graphs, where directed links represent causal relationships between the variables of a system that are represented as nodes (Charniak 1991). Parent nodes exert influence on their child nodes. The states of each node encompass all possible conditions that the variable is likely to encounter. The relationships between the state classes are quantified by conditional probability tables (CPTs). There are different ways to populate CPTs, e.g. by learning from data or by using expert opinion (Stewart-Koster et al. 2010). BNs allow joint processing of many types of information including own observations, statistical data, expert knowledge, scenarios as well as potential actions such as management interventions (Bromley 2005). In contrast to perception graphs, Bayesian networks can integrate quantitative scientific knowledge and qualitative variables.

With regard to stakeholder participation, Bayesian networks can be used for knowledge acquisition, knowledge integration and knowledge visualization. They can help to achieve a joint problem definition and to improve the stakeholders’ system knowledge as well as awareness of uncertainty (Zorrilla et al. 2009). Regarding environmental management, stakeholder participation is important to create ownership and acceptance for jointly identified management strategies. The participatory construction process of Bayesian networks is therefore as important as the final results (Lynam et al. 2002).

3.3 Participatory scenario development

Scenarios describe a sequence of future events in plausible and consistent ways. The most important interrelationships of the system components are considered and if-then statements are used in scenario development. It is important to bear in mind that scenarios are not forecasts or predictions (Schwartz 1998).

Involvement of stakeholders in scenario development has many advantages. During scenario generation, stakeholders reveal their knowledge and the problem perceptions. They learn to practice thinking about the future in a consistent and creative way, and improve their systems knowledge. Participatory scenario development enriches scenarios and ensures that all major uncertainties and different perspectives of stakeholders are taken into account. Furthermore, participation can also lead to shared understanding among potential users and their feeling of ownership of the scenarios (Pahl-Wostl 2008).

4 SUSTAINABLE ENERGY SUPPLY IN GROß-GERAU (HESS), GERMANY

Changing the energy system of a region towards a climate neutral system requires a region-specific strategy that joins the forces of a broad range of stakeholders. We support the Energy Competence Center of Groß-Gerau (a county in Hesse, Germany) to accelerate the production of renewable energy within the country by implementing a participatory process which takes approximately one year.
We apply actor-based modelling, Bayesian network modelling and participatory scenario development to support transdisciplinary knowledge generation in the field of a sustainable energy supply in Germany. The problem is related to a complex human-environment system, and the cooperation of different stakeholders is required.

Knowledge integration from outside of academia is one of the characteristics of transdisciplinary research. To reach this goal, stakeholders have to get the possibility to share their knowledge among each other and with scientists. Our approach consists of the following steps. Step 1, 2, 4, 5, 6, 7 include stakeholder involvement:

1. Interviews with relevant stakeholders to identify the perception of different stakeholders.
2. Generation of perception graphs (PGs) of individual stakeholders based on the interviews using DANA (section 3.2) and sharing of PGs within the group of stakeholders in a workshop.
3. Calculation of actions under different frameworks for scenario analysis and to merge the individual PGs into an overall PG (Analyst’s PG) including goals, factors and actions from the analyst’s perspective.
4. Discussion of analyst’s PG in a second workshop and construction of a Bayesian network (BN) (section 3.3).
5. Development of alternative scenarios in a scenario workshop (section 3.3).
7. Repeating step (1) to evaluate knowledge integration by identifying perception of the stakeholders.

Fourteen institutional stakeholders from the region are involved, including environmental organizations, municipal energy suppliers, network operators, a bank, a farmers’ association, the county Energy Competence Center, a regional planning institution, a research institute and an energy consultant. A total of fourteen semi-structured interviews were conducted mostly before the first workshop. During the interviews, PGs were produced by the representatives of the institutional actors, and they were verified by the representatives before or during the first workshop. In addition, causal networks for four energy sectors (biomass, photovoltaic, wind and geothermal energy) were developed during the workshop (Figure 3). In a second workshop, the analyst’s PGs for each sector were modified together with stakeholders and a common problem perception and a scenario framework were developed. In the third workshop, normative scenarios were generated. Participants were asked to step into the future (in this case 2020) and look backwards on the storyline how the goal has been reached from year 2012 on. The fourth workshop will take place in September 2012 aiming at identifying strategies based on the results of actor modelling, scenarios and Bayesian network modelling. A Bayesian network will be constructed based on the analyst’s PG in the mean time. For the Bayesian network construction, additional interviews with stakeholder are planned. We will evaluate the process as well as the adopted participatory methods with regard to successful knowledge integration.

First results show the increase of system knowledge among the regional stakeholders. For example, the interconnectedness of actions on a national scale and their consequences for the county seemed to have been unclear at the beginning of the process. Figure 2 shows the identified causal network representing the common perception of the stakeholders for the category solar energy.

5 DISCUSSION

In our transdisciplinary research, three participatory methods have been selected for supporting the integration of stakeholder knowledge in the development of sustainable management strategies. In this study, we aim at evaluating the
combination of actor-based modeling, Bayesian Network modeling and participatory scenario development applied in the participatory process. Integration of different knowledge types in transdisciplinary research are supported by actor-based modelling. System, target and action knowledge is captured in the stakeholders’ PGs and the analyst’s PG. The following scenario development enables a selection of robust actions under future conditions determined by the stakeholders. Final construction of BNs takes the uncertainty of the effectiveness for different management actions in the problem field into account and therefore support the identification of strategies for the accelerated implementation of renewable energies in Groß-Gerau.

First results show an increase in system knowledge among the stakeholders that are involved in the participatory process. Each workshop ended so far with a written feedback by the stakeholders. The feedback focused on knowledge integration with answering the question: “To what kind of new conclusions did you come during the workshop?” We received a positive feedback regarding the constructive atmosphere during the workshops. Stakeholders complained about focusing too much on the actor-modelling method during the first workshop. We think, however, that the introduction of the actor-based modelling was too short due to limited time. A more intensive introduction into the software might have increased the stakeholder’s acceptance and might have created a sense of ownership among the workshop participants.

![Diagram of Analyst’s PG (actions, factors, prospects) for the category photovoltaic energy. This PG forms the basis for BN modelling.](image)

6 CONCLUSIONS

Transdisciplinary research has the potential for the integration of stakeholder and disciplinary knowledge. This approach is crucial to the success of management strategies as stakeholders are directly involved in the participatory research process. In our transdisciplinary assessment, we intend to investigate the described participatory methods to understand whether and how they can be applied with regard to success for transdisciplinary knowledge integration and social learning.
ACKNOWLEDGEMENTS

We thank the two reviewers for their helpful comments and recommendations. This research was partially funded by the German Federal Ministry of Education and Research (BMBF).

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