Ambio 2015, 44:750–765
DOI 10.1007/s13280-015-0670-8

REVIEW

A functional-dynamic reflection on participatory processes in modeling projects

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Received: 1 May 2014 / Revised: 11 December 2014 / Accepted: 21 April 2015 / Published online: 22 May 2015

Abstract The participation of nonscientists in modeling projects/studies is increasingly employed to fulfill different functions. However, it is not well investigated if and how explicitly these functions and the dynamics of a participatory process are reflected by modeling projects in particular. In this review study, I explore participatory modeling projects from a functional-dynamic process perspective. The main differences among projects relate to the functions of participation—most often, more than one per project can be identified, along with the degree of explicit reflection (i.e., awareness and anticipation) on the dynamic process perspective. Moreover, two main approaches are revealed: participatory modeling covering diverse approaches and companion modeling. It becomes apparent that the degree of reflection on the participatory process itself is not always explicit and perfectly visible in the descriptions of the modeling projects. Thus, the use of common protocols or templates is discussed to facilitate project planning, as well as the publication of project results. A generic template may help, not in providing details of a project or model development, but in explicitly reflecting on the participatory process. It can serve to systematize the particular project's approach to stakeholder collaboration, and thus quality management.

Keywords Modeling · Stakeholders · Review · Functions of participation · Transdisciplinarity · Interdisciplinarity

Electronic supplementary material The online version of this article (doi:10.1007/s13280-015-0670-8) contains supplementary material, which is available to authorized users.

INTRODUCTION

Stakeholders and science

It is apparent that science addressing sustainability issues is increasingly involved in societal processes in normative and value-related terms (Funtowicz and Ravetz 2001), which makes traditional environmental management strategies problematic (Rittel and Webber 1973; Ludwig 2001; Jakeman et al. 2011). Particularly, integrated modeling studies aim to enhance knowledge from the perspective of different disciplines and more thoroughly tackle the problem in focus. To deal with complex, contested, and messy, real-world environmental problems, one strategy is to involve a range of nonscientists[1] such as the general public and decision makers (Armitage et al. 2008). This practice is often denoted as "participatory." There is a considerable agreement that scientists need the participation of stakeholders and decision makers, i.e., those affected and those to implement scientific results to successfully address complex environmental problems (Pahl-Wostl et al. 2007). The general notion thus is that such processes facilitate knowledge integration and ensure the "social robustness" (Nowotny 2003) of model results and proposed solutions. Consequently, there has been an increasing tendency to include various kinds of decision/policymakers in scientific modeling projects, which deal with complex environmental problems (Jakeman et al. 2006; Mostert 2006; Reed 2008). The statistics shown in Fig. 1 clearly shows that the field of participation in

[1] In this paper the term *nonscientists* includes scientists not working in academia. There are of course scientists working in Research & Development departments of companies, for instance. Furthermore, in reality we assume a continuum between these poles and do not purport a binary view.

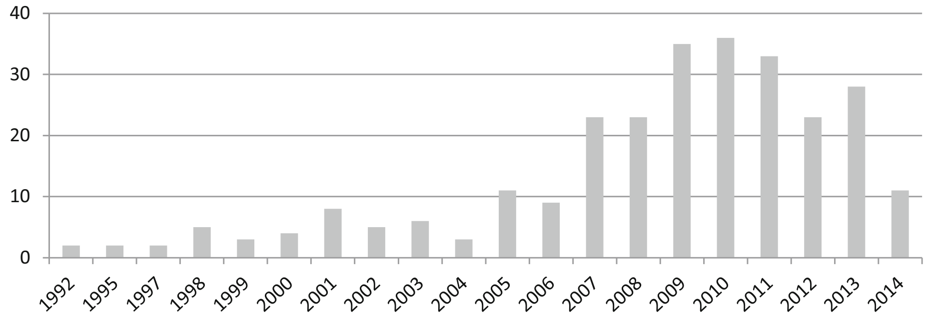

Fig. 1 Records in the Web of Science (WoS) database on participatory modeling studies published yearly in international scientific journals. Before 1992, no records could be found by searching for topic = ("participatory model*"). Timespan = 1960–2014. Date received: 4/29/2014

modeling studies has grown in recent years, with a peak in publications from 2009 to 2011. Participatory strategies have evolved particularly in integrated water management (e.g., Pahl-Wostl and Hare 2004; Giupponi et al. 2006; Barthel et al. 2010).

However, related to participation, challenges have to be addressed; despite the recent efforts to include stakeholders (to serve functions and goals such as knowledge integration and model use for decision support), several review studies indicate a general scientist–stakeholder gap (Lee 2006; Borowski and Hare 2007; Weichselgartner and Kasperson 2010). This may not be due to a lack of modelers' awareness of real-world problems relevant for stakeholders, but as mentioned for instance by Kok et al. (2009) modelers may underestimate challenges related to accomplishing science-oriented models and making them available to solve such questions. Particularly, nonscientists often do not use models developed for decision support, that is, models may be excellent in scientific terms but are more or less useless for practitioners (Olsson and Andersson 2007). The reasons for this range from inappropriate model assumptions or simply too complex models (Volk et al. 2010) to problems of legitimacy. Specifically, Alcamo (2002, p. 10) stated that "gaining this legitimacy should therefore be an important explicit goal of integrated modeling" and that "the basis for this legitimacy and how to gain it, has not been adequately studied and identified." A strategy to gain legitimacy is the inclusion of nonscientists in early project phases for data acquisition, definition of system boundaries, and problem framing. Essentially "the problem must be conceptually transformed and incorporated into a scientific discourse where it stimulates researchers to play with different models. The transformed problem, i.e., the research problem, becomes the shared research object that forms the starting point." (Elzinga 2008, p. 351) Moreover, Parker et al. (2002) discussed stakeholder participation in relation to issues of scales, models, and disciplines (i.e., interdisciplinarity [Id]). In line with other authors, they also stressed the need for dealing with different time frames and values (of and among scientists and practitioners) in the participatory process (Pahl-Wostl and Hare 2004), finding a joint goal, and managing the participatory process for the entire project duration.

These considerations are related to *transdisciplinarity*[2] (Td) (see e.g., Hirsch Hadorn et al. 2008; Mobjörk 2010) and *transdisciplinary research* (Scholz et al. 2006; Pohl and Hadorn 2007; Pohl 2011). This approach proposes an explicit reflection on joint leadership on equal footing between representatives from the science community and legitimized decision makers. In other words, Td "occurs with the claim to achieve, in addition to scientific knowledge, a concrete benefit for society and to contribute to a transformation or solution of current societal problems" (Stauffacher 2011, p. 264; translation by the author). Therefore, knowledge integration is one of several topics addressed by Td, as well as consideration of value conflicts and divergent interests among stakeholders and the general public (Voinov et al. 2014). Thus, Td is fundamentally about mutual learning between science and society and embodies the mission of science *with* rather than just *for* society (Seidl et al. 2013a).

This paper approaches participatory processes and modeling from the perspective of *transdisciplinary research* and asks what functions such processes may have in modeling studies. Hence, the goals of this paper are as follows:

- First, to systematize what participatory approaches in modeling projects and case studies have been implemented and
- Second, to highlight issues related to the participatory process, the modeling community, and the Td community, respectively, which so far may not explicitly be aware of. What information is given and challenges are reported by authors of participatory modeling studies?

[2] Note the multiple interpretations of the term transdisciplinarity (for discussions, see e.g., Rosenfield 1992; Pohl and Hadorn 2007; Thompson Klein 2010). In this paper, I use the term to differentiate between *interdisciplinary* work among scientists (from academia) and Td, that is, joint work of scientists and individuals from practice.

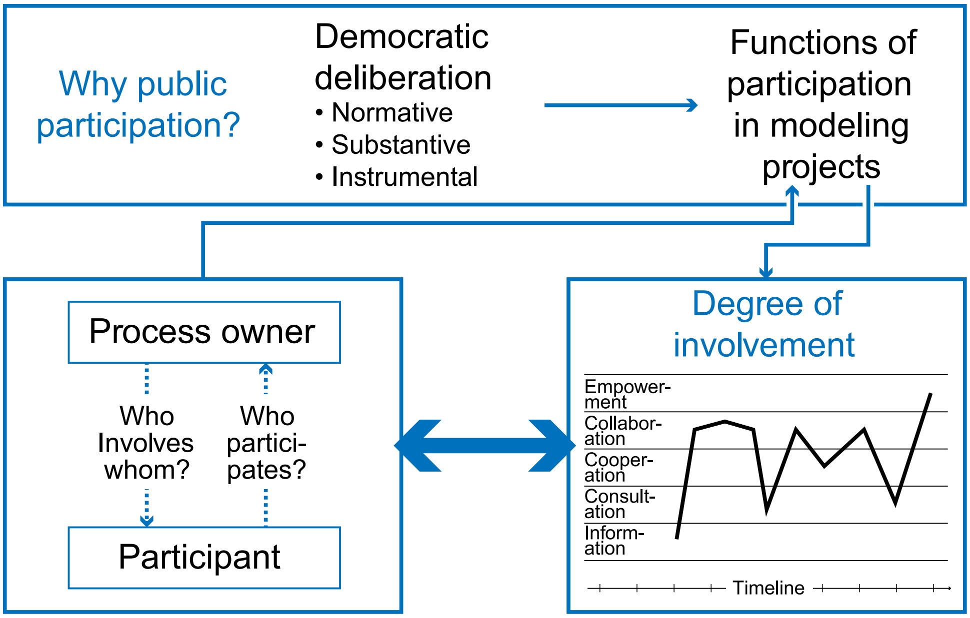

Fig. 2 What is expected from participation on societal and project levels (*upper section*) and two perspectives on one process (*lower section*): The *process owner*'s perspective is not the same as that of the *participant,* but both define their respective *degrees of involvement* during different project phases. (Figure adapted from Krütli et al. 2010). The process owner particularly influences the *functions* of participation

Participatory process

To participate, from the Latin *participare*, means to "take part" or "be involved" (Kipfer 2001). This indicates two questions, as illustrated in Fig. 2: *Why participation*? and *Who involves whom (to what degree)*? On one hand, the first question relates to democratic deliberation about participation in general and to discourses of democratic societies (Durant 2011). Fiorino (1990) identified three general approaches in participatory deliberation processes (see also Stirling 2006): normative democratic, instrumental, and substantive. *Normative* considerations urge societies to engage the public in decision making more generally, whereas *substantive* deliberation is based on the conviction that the quality of decisions is improved if participation takes place. *Instrumental* imperatives focus on a more effective justification of decisions made (only). Some authors found various interpretations of participatory processes, and more detailed categorizations of functions of participation have been developed. Rosener (1975; see also Rowe and Frewer 2005) found 14 functions, including "solicit impacted groups," "disseminate information," "resolve conflict," and "facilitate advocacy," whereas Walters et al. (2000) highlighted five functions: discovery, education, measurement, persuasion, and legitimization. As a third example, Stringer et al. (2006) proposed five functions of participation in the adaptive management context: more robust factual base, reduce uncertainty; insights into values; allow control, increase legitimacy; political concern to empower people; and foster social learning. In the following sections, I refer to Fiorino's (1990) basic distinction because it is simple enough, while covering the main distinction and is widely used in different (disciplinary) contexts.

On the other hand, the first question relates to the functions of participation in modeling projects in particular. This functional dimension of this study's perspective asks what purpose participation serves at different phases of a modeling project. The important challenge, noted for instance by Liu et al. (2007), p. 646), is to fulfill different needs of society and produce usable knowledge in modeling projects. I suggest that—embedded in democratic deliberation on participation in general—scientific projects aim at goals and identify (more or less deliberatively) certain functions of participation as being important to achieve these goals.

The second question (i.e., on involvement) relates to the relationship between the participant and the process owner and the degree of involvement (with the participant and the process owner having different perspectives on the same process). The upper section of Fig. 2 exemplifies the influence of democratic deliberation about the role of participation on the (expected) functions of participation in scientific modeling projects. The functions are also influenced by the process owner's expectations and reasoning (lower section of Fig. 2). The functions in turn considerably influence the participants' degree of involvement in different phases of a modeling process (with respect to the project lifetime). The illustration is meant as an example process with the line indicating different degrees of involvement over time, from information at the beginning, later reaching collaboration, and finally empowerment.

Krütli and colleagues (2010) addressed this issue by introducing two perspectives on one joint process. The first is the more common perspective of the process owner, who is typically the (academic) researcher in the case of modeling projects. He or she involves nonscientists according to the research plan and/or based on actor analysis. However, the process owner may also be a government department or a company representative. The second perspective refers to the actors addressed from outside academia. Participants actually have their own rationales and motivations to participate and formulate goals or interests that typically differ from those of the scientist/modeler (Eversole 2003; illustrative examples fom the development context are shown in Francis and James 2003, but in general, see Pohl et al. 2010). Both parties agree on the issues to investigate, which in turn determine the methods applied.

Previous reviews about participatory elements in modeling projects (e.g., Barreteau et al. 2010; Voinov and Bousquet 2010; Barreteau et al. 2013) proposed categorizations and identified functions of participation in modeling projects. In contrast, for instance, Schmitt Olabisi et al. (2014) took a different perspective, focusing on the functions *of* models, and modeling *within* participatory projects (for example, knowledge integration, addressing types of uncertainties, and generating consensus among stakeholders). Sometimes, both perspectives are mixed. This paper links to the first notion and asks which functions of participatory processes in modeling projects (studies) prevail and if Td-like processes have been established. The analytical components introduced above are detailed in "Functional-dynamic perspective on participatory processes" section. "Analysis and results" section shows the collection process and analysis of the reviewed articles. "Results" section then presents the results of the analysis. A general framework or template for Td processes in modeling studies is introduced in the discussion of the results.

FUNCTIONAL-DYNAMIC PERSPECTIVE ON PARTICIPATORY PROCESSES

All three approaches mentioned above (*normative, substantive,* and *instrumental*) may directly or indirectly frame a particular project (see Fig. 2, upper left section). However, the degree of reflection on this point varies in concrete projects (Korfmacher 2001). By reflection, I mean awareness and anticipation of the process and various functions during different phases. How explicitly have these been planned and described? This question is applied to the review sample's articles. For instance, Webler and Tuler (2006) analyzed 10 case studies and pinpointed four perspectives (as they call them). First, *science-centered stakeholder consultation* has a clear utilitarian focus on progress in problem solving, and the purpose of stakeholder involvement is mainly collecting all relevant and important information. Second, *egalitarian deliberation* emphasizes empowerment of participants. Interestingly, Webler and Tuler argued that discussion of values is not essential because "disputes about values are not resolvable" (2006, p. 712). Nevertheless, stressing the notion of Td (as presented above) value issues is an essential aspect of such a process. Even if they cannot be resolved in every case (Rosendahl et al. 2014), they nevertheless have to be made explicit and discussed. Scientific findings actually compete with societal intentions and values for decision makers' attention, and scientists should dare to engage in value issues (Voinov et al. 2014). The perceived importance of values may differ among stakeholders and between them and researchers/modelers. Moreover, there are indications that even when individuals rate a certain value equally important, they may nevertheless differ in their attitudes, which can lead to misinterpretation of the other's standpoint (Seidl et al. 2013b). Third, *efficient cooperation* means including the responsible agency, which will then make a decision, as informed by recommendations. The "primary function of public participation here is to supply comment and feedback for the agency to consider when deciding what to do" (Webler and Tuler 2006, p. 712). The fourth perspective, *informed collaboration* is ends oriented and focuses on the progress made with respect to the central problems. Along this line, trust in authorities and technical analysis are more important than consensus. Hare (2011) proposed four categories (following the process phases he identified) based on the approach of Bots and van Daalen (2008). The perspective purported by these categorizations is more consistent with the "truth to power" idea by participatory methods, indicating that process governance is with the researcher (see also Henriksen et al. 2009). Barreteau et al. (2013) identified three basic *expectations* (as they called it) of participatory approaches in modeling. First, one expects to upgrade the quality of a simulation model. The second one is to improve the suitability of the simulation model's use. A third expectation of simulation is to support participation itself, introducing a different perspective, as indicated before (functions of models *within* participatory processes). Drawing on these studies, I present a set of eight functions for the analysis in "Frequency of functions" section.

Moreover, according to the intended functions, a certain degree of stakeholders' involvement (see Fig. 2, bottom right) can be inferred. For instance, "science-centered stakeholder consultation" asks stakeholders to support a

Table 1 Degrees of stakeholder involvement (Stauffacher et al. 2008)

Level of involvement	Brief definition
One-way communication	
Information	Inform stakeholders about the project and its results and conclusions from a scientific perspective
Consultation	Ask stakeholders for information (such as management practices or preferences), which is then scientifically analyzed
Two-way communication	
Cooperation/active involvement	Actively involve stakeholders in the research process, which is, however, clearly defined and structured by the scientists
Collaboration	Design and conduct the research process on equal footing with the stakeholders
Empowerment	Give stakeholders full power over the content and process

model by their expertise, whereas "model construction" requires cooperation during the phase of model development and programing. Arnstein (1969) proposed a differentiation of degrees of involvement in participatory processes, for example. Table 1 shows a detailed differentiation of degrees of involvement and a basic distinction between one-way and two-way interactions (see Stauffacher et al. 2008). From information to empowerment, the degree to which process owners and participants can influence the process and content, including process steering and decision making, varies considerably.

A question that remains is whether *more is always better*, as suggested by the "ladder" metaphor put forth by Arnstein (1969). The answer is often taken for granted or not explicitly addressed. For instance, Barreteau et al. (2013) discussed the levels of participation and phases of different intensities, including the role of power, but did not explicitly reflect on this "ladder" notion, whether more participation yields better results. Since it is not obvious that collaboration is generally better than information or consultation, such an assumption should probably be relaxed and reflected on more intensely (Krütli et al. 2010). To utilize the functional-dynamic perspective for this review, I summarize other publications' functions referenced in the beginning of this section and present eight functions in Table 3, together with the relative frequencies of each, as found in the reviewed studies. Addressing the degree of reflection also means assessing the declaration of basic information about the degree of involvement ("Interdisciplinarity" section), statements on what has been done with the stakeholders (i.e., data on stakeholders and methods applied, "Data on stakeholders and methods" section), and whether the project was also interdisciplinary ("Interdisciplinarity" section). As Td and Id share some challenges, this is an interesting point. Finally, I also consider specific findings ("Further findings: Specific types of participatory projects" section) and list the most frequent journals that published the sample's participatory papers ("Journals" section).

ANALYSIS AND RESULTS

Search in Web of Science database

The articles were searched using the Web of Science (WoS) database (http://apps.webofknowledge.com) and "all databases" (refined searches are indicated). In this paper, I consider published research articles but not conference proceedings or books. I applied several search keywords and combinations to capture the diverse terms used to describe this kind of research. To ensure that the articles have a strong focus on participation in modeling, I searched for these terms in the titles (not in the abstracts, etc.); still, some articles were beyond the scope of this review or off-topic. An example is a paper titled *A Macro–Micro Integrated Theoretical Model of Mass Participation in Genocide* (Olusanya 2013). I included terms such as "companion modeling," "participatory modeling," "integrated modeling and stakeholders," etc. I conducted the search on September 23, 2013 and restricted it to the last five years (2009–2013). Table 2 shows the full list and respective results. The "useful" hits have been included in a more thorough evaluation. For clarification, searching for the search terms in TOPIC (including abstract and keywords) would generate too many irrelevant hits such as Olusanya (2013). For example, searching for integrated model* participat* in TOPIC instead of TITLE would yield 1817 hits. Too many of such results would have to be discarded from the sample, with the essential ones remaining anyway.

In this review, I categorize the articles according to the four points introduced in "Functional-dynamic perspective on participatory processes" section (function, dynamics/phases, democratic deliberation, and degree of involvement). This step is done based on reading the articles, extracting the main topics and messages, as well as identifying the main functions of the participatory process in each case. The functions are introduced in "Frequency of functions" section and are used to categorize the reviewed articles. The approach in this paper

Table 2 Summary of results showing search terms and respective number of hits (the number used for further inquiry in parentheses). Timespan = Latest 5 years. Search language = English. February 19, 2013

Terms in title	Number of hits (useful)
Participatory computer simulation	1 (0)
Stakeholder computer simulation	–
Integrated model* participat*	12 (8)
Integrated model* companion*	1
Integrated model* stakeholder*	8 (7)
Participatory modeling	71 (21)
Transdisciplin* model*	11 (1)
Moderat* model*[a]	11 (0)
Companion model*	19 (3)
Model* stakeholder*[b]	25 (16)
Integrated* stakeholder*	9 (6)
Mediated modeling	3

[a] Refined by: Document Types = (Article) and Research Areas = (Remote Sensing or Environmental Sciences Ecology or Water Resources or Operations Research Management Science or Social Sciences Other Topics)

[b] Refined by: Document Types = (Article) and Research Areas = (Environmental Sciences Ecology or Forestry or Water Resources or Social Sciences Other Topics or Operations Research Management Science)

goes beyond the analysis of the degree of participation but combines the idea of the functions of participation in modeling projects at their different phases and explicitly presents a functional-dynamic perspective. It is important to note that I counted functions as they were intended by each study—neglecting the accidental side effects discussed in some papers (such as group facilitation). Nevertheless, the functions were not always stated explicitly; this needed some degree of interpretation, which, however, tried to be close to the statements, particularly in the respective abstracts and discussion sections. A study may be characterized by more than one function but often, foci can be identified.

Results

The Table S1 in the Electronic Supplementary Material shows the overview of all 38 articles reviewed and also contains columns about the explicit functional-dynamic reflection, type and number of stakeholders, and the modeling method applied. The table also includes a short characterization by topic, main purpose, and additional comments where indicated. I report on these aspects in this section.

Frequency of functions

Table 3 shows how often which functions could be identified in the reviewed articles. Utilizing the approach introduced above revealed that usually, more than one function could be identified for each study, but the functions were not always explicitly stated. Likewise, the authors did not always reflect on the functional-dynamic dimension. This may be because it did not matter for the articles from their point of view or because it was generally not reflected upon in their study. This of course may hint at a fundamental problem for modelers/scientists in academia to consider the context in which stakeholders work, their rationales, policy interests, etc. (Welp et al. 2006; Liu et al. 2008; Voinov and Gaddis 2008; Matthews et al. 2011). For instance, Gaddis et al. (2010) article covered process monitoring on different functions of participation but offered no explicit perspective on different functions (including degrees of involvement) at different phases of the participatory process.

A pattern of functions is visible by observing the frequency of certain functions. The majority of the articles aimed at gaining access to specific (stakeholder) knowledge (function 2, $N = 24$), usually done at the preparatory phase and normative in nature. To facilitate group processes among stakeholders was the second most frequent function (function 8, $N = 18$). At least 16 projects aimed to yield socially robust solutions (function 7). Function 1, the early inclusion of stakeholders into the modeling process for joint problem framing etc., was highlighted as essential by cited reviews in the introduction but not too frequently applied in the current sample. In total, 15 studies could be assigned to this function. However, compared to a prototypical Td process (as defined above), there was seldom a joint problem definition, etc. Martínez-Santos et al. (2010) described one such example, reporting a water management study in Spain that included different actors with conflicting views. Interestingly, the stakeholders defined the research objectives. Particularly, they agreed to implement a groundwater flow model and to use the Bayesian belief network modeling approach to consider socioeconomic aspects. One intended effect of the project was that to help with solving the conflict situation between the respective actors (function 8). Scenario and indicator development was another function identified in the studies (function 3, $N = 11$), with five times being the explicit main goal (e.g., Gaddis et al. 2010; Franzén et al. 2011; Molina et al. 2011; Mazzorana et al. 2012). Decision makers and stakeholders were asked 10 times to use the model itself or the models' results for adapting their decisions (function 6). There were huge differences regarding the progress and success of this function, comprising planned or intended use (Thompson et al. 2010; de Mey et al. 2011), largely failed cases (Squires and Renn 2011), and general success stories (Gaube et al. 2009).

An explicit reflection on the functional-dynamic nature of the participatory process within the project could be identified in 13 cases. In some cases, the Td process had been illustrated by a timeline or in a detailed table.

Table 3 Frequency of the eight functions (total number of reviewed articles, $N = 38$). Functions of participation in society and at different phases of modeling projects, suggesting certain degrees of involvement. Categories of democratic deliberation are indicated (* normative, £ instrumental, # substantive)

Democratic deliberation/degree of participation/phase			Functions of participation in modeling project	Frequency in sample
Preparation phase	Core phase	Phaseout/follow-up		
Cooperation*			1. Joint problem framing: formulate research goals and questions, as well as system boundaries, so that real-world problems are addressed	15
Consultation*			2. Gain access to specific knowledge, as well as to cognitive framing and perceptions	24
	Consultation* Collaboration#		3. Develop scenarios and indicators to capture the relevant concepts from both science and practice perspectives	11
	Information£	Information£	4. Inform decision makers about state-of-the-art science; present results	14
Information£		Information£	5. Gain access to policymakers/decision makers, i.e., influence decisions	11
		Cooperation£/#	6. Ask decision makers to use the developed models or achieved model results	10
Collaboration/ empowerment#	Collaboration/ empowerment#	Information£	7. Yield socially robust solutions (i.e., those that are accepted by decision makers and the general public)	16
	Collaboration/ empowerment#		8. Facilitate group processes and social learning	18

However, not all of these cases went beyond a fragmentary description of what had been done (e.g., a series of workshops, lacking the explicit functions and respective degrees of participation). This may illustrate a lack of deliberative consideration of the functional-dynamic nature of the process or may result from the focus of the respective articles (scientific results rather than the Td process). The reason cannot be inferred from the review results.

Degree of involvement

Some studies explicitly refer to the ladder of participation (e.g., Elbakidze et al. 2010). The degree of participation (inferred from the functions identified and stated more or less explicitly by the studies) ranged from information to collaboration, with the latter less frequent. The respective numbers for each category of degree of involvement are as follows: consultation ($N = 25$) and cooperation ($N = 21$) were quite frequent, whereas information ($N = 12$) and collaboration ($N = 8$) were less frequent.

Data on stakeholders and methods

Several papers offered no information about some aspects, for instance, the type and actual number of stakeholders involved, in 3 and 10 instances, respectively. Where numbers were given, the range was broad; 7 to 60 stakeholders had been involved. Regarding applied *methods*, "workshops" or "meetings" were mentioned most often. One paper did not provide the background about the events organized or the method applied. The more frequently used specific methods were role-playing games ($N = 3$) and questionnaires ($N = 3$). With respect to modeling, agent-based models ($N = 12$) had been applied rather frequently, and also system dynamics ($N = 8$) and Bayesian approaches ($N = 4$). Again, sometimes information was lacking, and the modeling method was not always explicitly revealed and explained. A detailed account of each paper's information about the *type and number of stakeholders* involved, types of events or procedures, modeling method applied, and resulting degree of participation can be found in the appendix.

Interdisciplinarity

Eighteen studies could be described as interdisciplinary, and some mentioned (in addition to Td) the resulting challenges from Id. For instance, Langsdale et al. (2009), p. 308) reported on how "single disciplinary researchers gained new perspective from the relatively simple, high-level multidisciplinary model." Another case reported that agent-based modeling had been applied "as the most suitable modeling paradigm in order to: integrate [both] the participation of stakeholders and the Id character of the research team" (Simon and Etienne 2010, p. 1373). This learning by knowledge integration (here using modeling) was thus mentioned as important. However, it did not seem a unique challenge to Id but also held true for a transdisciplinary crossover. Röckmann et al. (2012), p. 1082) concluded that participatory modeling might be expected to be a panacea to integrate all types of knowledge from diverse sources; however, "practical implementation is difficult." Another study found that discussions about 'disciplinary epistemic stances' might take more time than available in a research project (Leclerc et al. 2009). However, Sandker et al. (2010), no page number) found greater challenges related to "reconciling the diverse views of the stakeholders involved […] than to the disciplinary mix."

Further findings: Specific types of participatory projects

The companion modeling (ComMod) approach appeared relatively frequently ($N = 10$) in the sample (Batten 2009; Leclerc et al. 2009; Campo et al. 2010; Lagabrielle et al. 2010; Naivinit et al. 2010; Ruankaew et al. 2010; Sandker et al. 2010; Simon and Etienne 2010; Worrapimphong et al. 2010; Barnaud et al. 2013). Projects using this genuine participatory approach usually produce (most often agent-based) models representing local/regional societies and respective environments that aim to make actors' decisions explicit, elicit discussion, and facilitate solutions to the problems. I would consider this a particular pattern of functions because this approach is participatory and integrated but with a different aim—not predominantly developing scientific models but enhancing communication and problem solution among local communities by means of modeling as a tool *within* participatory processes. This case is also reflected by the results of this subsample. For instance, in ComMod studies, the most frequent function was to "gain access to specific knowledge" ($N = 9$), followed by "facilitation of group processes/social learning" ($N = 7$). In contrast, it was not particularly relevant whether local decision makers used the developed models/model results ($N = 0$) or that "a joint process to formulate research goals and questions" had occurred ($N = 2$).

Journals

This review also found that some journals had published participatory studies more frequently. The *Environmental Modelling and Software* journal (11 articles) seemed an important publication for these studies. More than once also, the following journals appeared in this sample: *Ecological Economics* (2), *Ecology & Society* (4), *Marine Policy* (2), and *Mitigation and Adaptation Strategies for Global Change* (2).

DISCUSSION

In this paper, a sample of modeling studies that include a participatory component has been reviewed against the background of an explicit functional-dynamic process perspective and a Td approach. Given the potential mutual fertilization between system science knowledge (i.e., systemic-functional structuring of ill-defined problems) and the nonscience knowledge of stakeholders, the aim is to meld the system science perspective represented by models into a multistakeholder discourse to tackle the social complexity of a problem at hand and acknowledge that there are different types of knowledge on critical issues from different perspectives. Stakeholder processes may help improve both aspects, as often assumed. Extended participation may yield better results in terms of fulfillment of the functions (Evely et al. 2011). This is all the more important in participatory modeling because here we have the model as a product that is often only really useful if stakeholder input and acceptance are given. For instance, the degree of success of a participatory process can be read from stakeholders' trust in modelers' expertise and the amount and quality of information they give, as well as whether they intend to use the model and/or its results and will actually continue in future collaborations. Failed processes may result in lack of interest and refusal to give data or use/apply the model or its results. A better awareness of the intricacies of the participatory process should improve the intended functions' impacts. Overall, the inclusion of stakeholders should proceed in a structured way, be taken seriously, and thus be planned beforehand. An example for such a rather well planned and successful process can be found within the Ateam project(https://www.pik-potsdam.de/ateam/stakeholderweb/ateam_stakeholderstart.html). Though from this project no articles have been reviewed in this paper, one can highlight how for the different modeling tasks have been linked to stakeholders' expertise and expectations. Furthermore a final evaluation was performed by the stakeholders to assess the usefulness of the project results (Schröter et al. 2004).

To collect a valuable sample of articles, the search in WoS has been broad but restricted to the titles. Nonetheless, a vast diversity of approaches is reported in the reviewed articles. Apparently, there are genuine, integrated modeling projects and participatory projects that also include modeling but have a different motivation such as social learning (Reed et al. 2010; Cundill and Rodela 2012). Articles describing larger integrated projects that couple different disciplinary models are rather seldom and therefore not frequent in the current sample. This kind of projects may integrate different disciplinary models (e.g. Glowa-Danube, ATEAM) but often do not highlight participatory modeling in the paper titles, although they may well incorporate a level of participation. (see, Schröter et al. 2005; Barthel et al. 2010). As can be derived from the current and previous reviews, different branches begin to emerge and be established. For instance, 10 of the reviewed articles (27 %) count as employing the ComMod approach. These represent an emphasis on models as tools for inter- and transdisciplinary communication (Sterk et al. 2011;

Schmitt Olabisi et al. 2014). This relatively high percentage in this sample also hints at the usefulness of applying a clear strategy and a conceptual framework, based on a lot of team expertise (http://cormas.cirad.fr/ComMod/en/). Moreover, there are examples of projects that do not stand for a specific tradition (Smajgl 2010; de Mey et al. 2011). Interestingly, among those articles explicitly citing functional-dynamic process issues, none follows the ComMod approach but each comes from a different modeling community (Smajgl 2010; deReynier, Levin, and Shoji 2010; de Mey et al. 2011; Franzén et al. 2011; Molina et al. 2011; Salerno et al. 2010; Squires and Renn 2011; Vayssieres et al. 2011) or addresses "mediated modeling" (Vayssieres et al. 2011).

Starting a Td process to reach consensus about the goal can be targeted between stakeholders and scientists. This can be perceived by scrolling through the sample, where 15 studies apply such a function. However, it is important to do justice to each study and its specific context and focus, as well as to the individual financial and temporal constraints. As for the degree of involvement, each function serves a fundamental goal of a project. It is not the purpose of this review to rank the studies by the number of functions they address (the more the better). Rather, it is important to obtain a structured overview of the diversity of functions in different studies and how explicitly authors reflect on participatory processes. This review is a further step to this end. Volk et al. (2010, p. 845) concluded that "further emphasis must be placed on stakeholders developing a clear vision [of] what they need and want." However, this issue cannot be easily resolved during the project process. Thus, Volk et al. (2010) "have learned that it is far easier to design a DSS [decision support system] for a group of stakeholders who actively participate in an iterative process." In their presentation of a typology of modeling approaches and tools for formalizing stakeholder knowledge, Voinov and Bousquet (2010) also proposed the joint development of research questions and goals. Hence, the decisive factor seems to be the early inclusion of stakeholders and prospective users of these systems into the modeling process (Díez and McIntosh 2009). Therefore, a gap remains between the regulative idea of early inclusion of stakeholders and the reality in many modeling projects.

In this regard, a more structured approach would most probably be helpful in many cases, first to raise awareness of the complexity of participation added to a project, and also to show the potential by highlighting various functions at different project phases. Nonetheless, many projects start their collaborative/participatory processes from scratch without reflecting too much on the particular functions of the involved actors during different phases of the project. For instance, Sievanen et al. (2012) stated that several studies they reviewed had mentioned the absence of a generic framework as a problem. Moreover, Reed (2008) argued that an emphasis on the process should replace a "tool-kit" approach. It is likely helpful to pay particular attention to the planning of the time frame and the functional-dynamic aspect of an orientation template (Röckmann et al. 2012). In drawing on the experiences of Td research and the more extensive literature (including this review), it is worthwhile to think about using such a framework or template to help modelers and scientists in general to consider and plan beforehand several issues important in Td processes.

Liu et al. (2008) identified phases that might be designed in different ways, for instance, including stakeholders' interaction to inform them about scientific knowledge or collaborate in a scenario analysis. In other words, as Wiek and Walter (2009) pointed out, a structured process perspective is vital but may differ from study to study. The dimensions highlighted in the previous sections are considered within a general template for Td processes put forth by researchers in Switzerland (Stauffacher et al. 2006; Scholz 2011; Seidl et al. 2013a). This approach is explicit about the participants' functions during a participatory process and generic regarding its openness to several types of cases and across different human-environment system problems. Researchers from different domains could refer their case or project (or funding proposal) to this general template but also design their project according to the most important functions. They could more deliberately choose an appropriate approach instead of starting with rather rough ideas and muddling through afterwards. Figure 3 adapts and extends this approach and illustrates different phases and related functions of Td processes. It represents a prototypical Td process and in this sense, an ideal or a regulative idea, more than a typical process. It also abstracts from specific project developments and depicts a succession of steps often found in participatory projects. Of course, the sequence is not fully determined and loops may occur between certain steps or goals or priorities may be adapted. During some phases/steps, the parties involved collaborate more closely or work on their own (adjusting the degree of participation to the respective function). Usually, legitimized decision makers, the science community, and the general public can be distinguished. Referring to Fig. 2, any of these actor groups can become the process owner; however, most often, the scientists assume this role. This predominance of scientists in the role as process owner could also be discussed. As highlighted by Stirling (2008), power relations may not be solved just by introducing participatory elements. The content, that is, the topic of a particular project, may influence the actual application or configuration of a specific process design. After formulating a plan of action, deciding how to investigate a problem—as identified by scientists or other

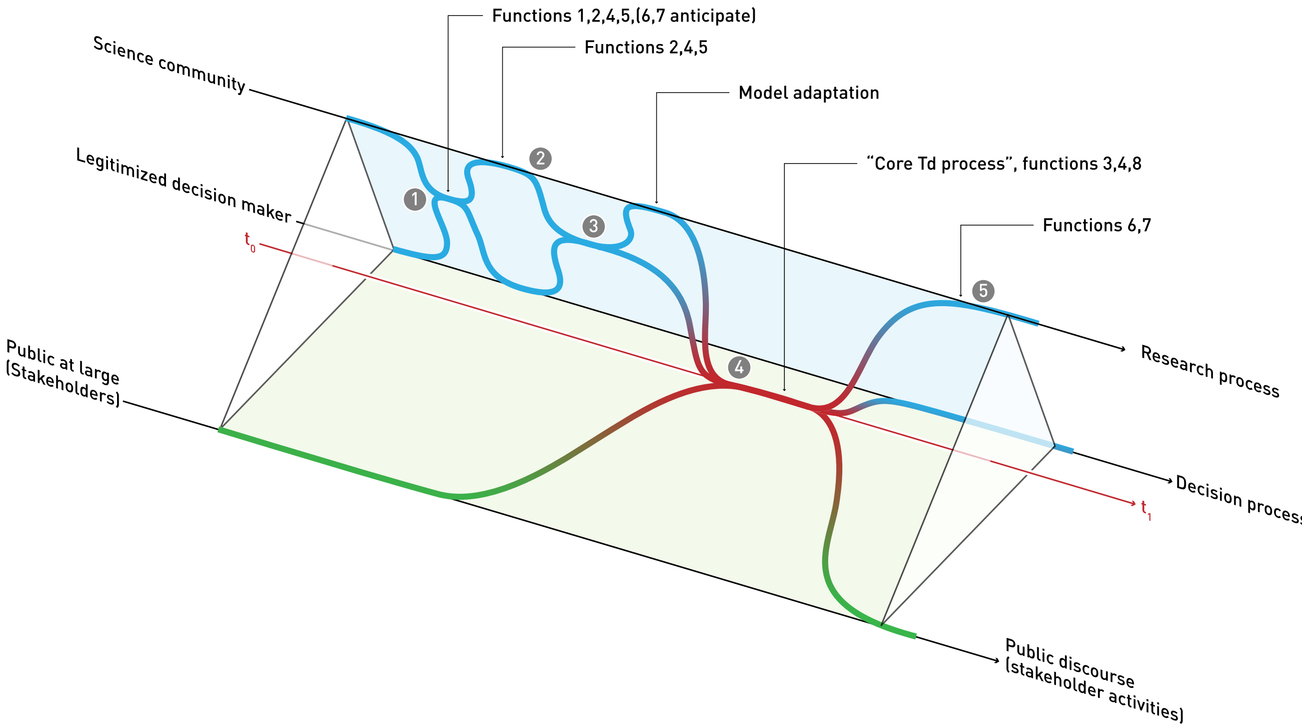

Fig. 3 Illustration of the functional-dynamic nature of Td processes: various functions at different phases are highlighted for modeling projects. (Adapted from Fig. 1 in Seidl et al. 2013a)

actors—and performing a (first) stakeholder analysis, several steps follow:

1. Scientists usually meet with the decision makers to discuss the issue and set possible goals for the project (including system analysis and representation). This step can represent functions 1, 2, 4, and 5. It is also valuable to ensure that decision makers in the end have legitimacy to make decisions later and that models or their results are actually used within the subsequent decision-making processes (functions 6 and 7).
2. Next, scientists and modelers develop a first version of the model, highlighting functions 2, 4, and 5.
3. Then the results of this model version and potential management options identified may be discussed with decision makers.
4. Subsequently, model adaptations may be necessary during an "ideal" or "core Td process" members of the public (who are affected by any possible decisions made) join the process. In this step, all stakeholders and scientists can meet, for example, in a modeling or scenario workshop (using scenario analysis and visualizations of the model's results). This phase refers principally to functions 3, 4, and 8.
5. The final phase implements the management options or planned actions (involving functions 6 and 7). Then the Td process comes to its (scheduled) end; the parties return to their core business.

However, one should evaluate if mutual learning and capacity building have occurred (Walter et al. 2007; Jones et al. 2009). The template's actual form is debatable, but I believe that for modelers who are inexperienced with Td processes, it is important to explicitly consider the fact of *various* stakeholders who may serve *diverse functions* at different process *phases.* Seeing these processes clearly represented by Fig. 3—and probably drawing a particular project's process as anticipated in such a way—facilitates the understanding and proper preparation of respective stakeholder contacts. Such a generic template may help, not in providing details of a project or model development, but in explicitly reflecting on the participatory process. It can serve to systematize the respective project's approach to stakeholder collaboration and thus facilitate quality management of participatory modeling.

The review also shows the absence of a standard protocol on how to *report* Td-modeling project results. Suggestions have been made for agent-based approaches such as the overview, design concepts, detail (ODD) protocol (Müller et al. 2013). I do not recommend using a particular guideline, but in my view, authors using an integrated modeling approach with an emphasis on scientific results should answer the question, *How explicit should we consider the participatory aspect in our modeling paper?*, given that the scientific process and its results are complex in themselves. One option is to write a couple of papers, one focusing on the scientific results (model development and application, results, and new insights) and another describing the participatory process (stakeholders' roles and functions and their influence on the model's results or validity). For instance, Videira et al. (2009, 2010) published two papers on the same project, each with a different focus and in different journals. A comparable option had been chosen by Vayssières et al. (2009, 2011).

Some studies in this review are also interdisciplinary in nature ($N = 18$). Not all the respective authors reflect on this aspect but some hint at challenges such as knowledge integration. An additional point discussed in the literature on Id and worth mentioning here refers to the differences and commonalities between participation (or Td) and Id. What can these two approaches learn from each other by reflecting on their inherent processes? Several common challenges of Id and Td can be identified; Id also generates complex interaction patterns and communication problems among different disciplines (Bradshaw and Bekoff 2001; Pennington 2008; Schmitt Olabisi et al. 2014). Nonscientists' participation in Id research projects then adds another level of complexity, which is not always well anticipated and integrated in project planning (Prell et al. 2007) yet requires appropriate planning and integration methods (Huber et al. 2014). Moreover, language and cultural aspects are as challenging between disciplines such as social psychology and hydrology, as they are between the researcher in hydrology and stakeholders from the administration or private companies (on this discussion, see Stokols et al. 2008). The Id processes in a project can also be conceptualized in terms of Td acknowledging differences in culture, language, and rationales—not among stakeholders but across disciplines (Snow 1959; MacMynowski 2007). The idea to integrate different cultures and knowledge systems also raises the issue of the (future) role of disciplines. Against this background, the idea proposed by Bradshaw and Bekoff (2001) to "incorporate" social science into biophysical research (i.e., conceptually including humans in the ecosystem) sounds somewhat strange, still presuming (at least implicitly) a predominance of the natural sciences. Nevertheless, the authors stated the need for natural sciences to open up and relate to the social sciences because the latter is stronger in transdisciplinary and qualitative work. Thus, social scientists are often perceived primarily as facilitators responsible for the communication process with stakeholders. For instance, (Gaddis et al. (2010), p. 1437) argued, "While the modelers were taking care of the model development, social scientists were providing important insight about group dynamics and helped identify particular problem areas in stakeholder interactions." However, their suggestion to consider the human experience as an original context for science is very welcome. Still, different notions have been proposed about how the sciences will or should develop. Are social sciences primarily responsible for integration (Wäger et al. 2014)? Will (or should) disciplines dissolve into a meta-discipline? Other voices demand the emergence of an Id discipline, for instance, *TD* (Pohl 2011) or *integration and implementation sciences* (Bammer 2014), to replace the current "fragmentation and unorganized diversity" (see also Stokols 2006). In the final section, I indicate some ideas for the future discourse on Td modeling.

CONCLUSIONS AND OUTLOOK

The growing importance of stakeholder participation in research (modeling) projects is reflected in the increase of publications about participatory modeling studies (see Fig. 1). It may be speculated how the approach will develop. One point revealed by the current review is still the moderate awareness of the complexity of a participatory process. Thirteen out of 38 studies explicitly reflect on the participatory process in which they are involved. However, an analysis of the functions of participation in a given context may elucidate the deliberation on the nature of the specific process and its dynamics. I therefore encourage the modeling community to engage in *Td-modeling processes* based on a thorough analysis of their dynamics and the respective functions of different kinds of stakeholders. However, no standard template of a Td process has emerged yet. There are several reasons for this: some researchers/modelers do not know these approaches proposed by the Td research community, different schools emerge that follow specific paradigms appropriate to their aims, and some larger, integrated modeling projects have developed their own approaches from scratch. I suggest consulting a general template (as the one presented here), not following it strictly but eliciting the explicit reflection on process ownership, the stakeholders' functions at different phases, and the phaseout during the final stage of the process. Such a template should be open to different types of projects and modeling approaches.

For reporting results of participatory modeling projects, a guideline or convention would be helpful to reduce the considerable heterogeneity and facilitate the comparison of papers. A citation analysis of the set of articles reviewed in this paper is planned to gain a more detailed knowledge about who or what communities cite participatory modeling papers.

The literature shows that the gap between researchers/modelers and nonacademic individuals remains far from being closed, and too many projects neither acknowledge the complexity of Td processes, nor reflect on them, nor consider previous work on Td outside the modeling community. The last issue may be because the Td research community is unaware of its potential contribution or the discourse is largely outside the disciplinary boundaries of modelers. More often than not, funding depends on naming ‘some’ plan for stakeholder interaction in the proposal, which does not necessarily imply modelers also think it is important. Cabrera et al. (2008, p. 406) reported that in their study, fieldwork was “not always attractive to all scientists because it may be considered a time-consuming activity that in addition requires a special personality to engage [the] stakeholder.” Accordingly, some authors argued that modelers should enhance their facilitation and group process skills, acknowledging a model as a communication tool above its scientific value (e.g., Schmitt Olabisi et al. 2014). It surely does no harm to extend one’s skills, but personally, I doubt that this can be achieved comprehensively (educating all modelers who may be part of Td projects). Rather, I recommend including experienced facilitators (with any disciplinary background, why not hydrogeology?) through the phases of the Td process. Thompson et al. (2010, p. 755) experiences illustrated this point: “Finally, we recommend that workshop planning teams include formal expertise in both modeling and facilitation. In our workshops, the facilitators pushed the modelers to integrate the participants’ requests and insights into the model, while the modelers pushed the facilitators to introduce complex science and dynamic interrelationships to the stakeholders. This combination of modeling and facilitation expertise was integral to the successful development of a collaborative process for integrating scientist and local stakeholder knowledge about greenhouse gas emissions in an urban ecosystem.”

While several authors have stressed the importance of early “inclusion” of stakeholders in modeling projects (referring to function 1), it can still be asked, “How early is early enough?” Given that the problem definition and agreement on system boundaries should be carried out before modeling activities start, in order to increase the relevance of model outputs and project outcomes, does this not run counter to many funding agencies’ programs and calls? A critical exploration of the relationship between transdisciplinary research and societal problem solving is by “integrating user needs in research applications is usually done after the fact of a successful bid” (Polk 2014). Of course, the opening of a call for proposals represents political goals or societal needs in themselves. For instance, the experts of the “Horizon 2020 Advisory Group on ‘Science with and for Society’ (E03093)[3] ” are asked to answer the question, “What should be the main priorities needed to shape the next ‘Horizon 2020’ Work Program 2016–2017 to build an effective cooperation between science and society?” A staged review process that evaluates a pre-proposal or letter of intent before inviting some groups for a full proposal may also contribute to the selection of more problem-oriented research (Johnson and Hrynkow 2011).

The typical researcher knows little about the process that leads to the formulation of a call in the first place. Replying to a call, research groups aim to address the topic but do not usually cooperate with stakeholders in advance when writing the proposal. One alternative is that funding agencies work together with scientists, modelers, and stakeholders to pave the way for a Td process before opening a final call that is specifically tailored to researcher and stakeholder needs. Indeed, a recommendation of the Finnish Environment Institute (Mashkina et al. 2009, pp. 55–57) highlights early inclusion of stakeholders in a template for an ideal joint call for international project collaboration. Likewise, the European Union’s calls for proposals are preceded by interactions of the agency’s board with stakeholders and practitioners. However, this approach portrays considerable effort and a systematic way of establishing a participatory process, which presumably does not comply with Td standards, as nonscientist practitioners do not seem to be represented in these groups.

Acknowledgments The author thanks the four reviewers for their helpful suggestions to improve the paper, the colleagues Roland Barthel, Michael Stauffacher and Christian Pohl for discussions on earlier drafts of the manuscript, and Sandro Bösch for helping with the figures.

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[3] http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3093.

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