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Modeling with Stakeholders for Transformative Change

Anne van Bruggen [1], Igor Nikolic [1,*] and Jan Kwakkel [2]

1 Section Energy and Industry, Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands; annereina@gmail.com
2 Section Policy Analysis, Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands; J.H.Kwakkel@tudelft.nl
* Correspondence: i.nikolic@tudelft.nl; Tel.: +31-15-2781135

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Abstract: Coherent responses to important problems such as climate change require involving a multitude of stakeholders in a transformative process leading to development of policy pathways. The process of coming to an agreement on policy pathways requires critical reflection on underlying system conceptualizations and commitment to building capacity in all stakeholders engaged in a social learning process. Simulation models can support such processes by providing a boundary object or negotiating artifact that allows stakeholders to deliberate through a multi-interpretable, consistent, transparent, and verifiable representation of reality. The challenge is how to structure the transdisciplinary process of involving stakeholders in simulation modeling and how to know when such a process can be labeled as transformative. There is a proliferation of approaches for this across disciplines, of which this article identifies Group Model Building, Companion Modeling, Challenge-and-Reconstruct Learning, and generic environmental modeling as the most prominent. This article systematically reviews relevant theories, terminology, principles, and methodologies across these four approaches to build a framework that can facilitate further learning. The article also provides a typology of approaches to modeling with stakeholders. It distinguishes transformative approaches that involve stakeholders from representative, instrumental and nominal forms. It is based on an extensive literature review, supported by twenty-three semi-structured interviews with participatory and non-participatory modelers. The article brings order into the abundance of conceptions of transformation, the role of simulation models in transformative change processes, the role of participation of stakeholders, and what type of approaches to modeling with stakeholders are befitting in the development of policy pathways.

Keywords: modeling; transformation; collaboration; policy pathways; decision making; social simulation; social learning; transdisciplinary

1. Introduction

Global climate change constitutes an unprecedented challenge for humanity. Maintaining and developing production and consumption systems within planetary boundaries while increasing global prosperity has no straightforward solutions. Transformative, rather than incremental, change of our socio-technical systems is required when current system functioning becomes untenable. Transformative change must have "the reach to shift existing systems (and their component structures, institutions and actor positions) onto alternative development pathways, even before the limits of existing adaptation choices are met" ([1], p. 114). Over the last few years, a variety of policy analytic approaches have been put forward for developing or designing policy pathways [2–4].

Collaborative approaches can be characterized as 'transformative' when they support participants in formulating transformative policy pathways and action plans. Simulation models offer a way to support collaborative sense and decision-making, a core part of transformative change. By providing analysis, practicing science and bridging the gap between societal practices, simulation models can support the identification of policy pathways and scientific insights that were not available before [5]. Models lie at the heart of science and offer a powerful way to enhance and discipline our thinking in the face of complexity and uncertainty by exploring interdependencies in systematic ways helping us to formulate policy pathways [6,7].

Computer simulation constitutes a "third branch of science", which in addition to developing theory and doing experiments can generate knowledge [8]. Simulation models support transformative processes by offering a simplified version of reality; a negotiating artifact or boundary object that unites stakeholders around it [9,10]. The process of modeling involves different actors in a collaborative analytical and deliberative process. Through participation, transformative policy pathways can be formulated and action plans created in the face of deep uncertainty [11,12]. However, models can equally become 'useless arithmetic' or fig leaves behind which scientists and decision makers can hide if the model building is not accompanied by a strong social or qualitative process [13]. Furthermore, most modeling exercises fail to reach the goal of empowering stakeholders to take ownership of the sense and decision making process required for transformative change [14–16]. In the face of crises such as climate change, this ownership of the collaborative process is crucial if we are to make useful models to design, implement, monitor, and use (transformative) policy pathways [17].

The literature on participatory research, including the niche of modeling with stakeholders, is large and growing. However, the role and potential of this literature for supporting large transformative processes is not systematically outlined [18]. Over the past ten years, various literature reviews of modeling with stakeholders have been presented. Although the field is relatively young, there is a proliferation of approaches to decision-making processes involving stakeholders through modeling [16]. These approaches often aim at the same goals, use similar methodologies, but set different priorities and employ different terminology, theoretical references, and contexts [19].

The field of modeling with stakeholders and participatory research suffers from fragmentation due to:

1. scientific incentives and the not made here syndrome.
2. disciplinary biases.
3. fragmentation of research efforts across disciplines, academic societies and conferences, and journals.
4. the 'incoherency problem' in the social sciences.

The incoherency problem refers to the lack of a single fundamental understanding of what motivates human beings to cooperate and what their capacities are ([20], p. 1). The fragmentation hinders the development of the field as it prevents the identification of essential similarities and differences among existing approaches. Systematic learning about the approaches also requires a common conceptual framework of the role of simulation models in transformative change. The challenge is thus how to identify essential similarities and differences among various approaches within the fragmented field of modeling with stakeholders as well as articulate underlying mental models, principles, and concepts that make the field coherent and allows learning between approaches to occur.

The aim of this paper is to review the literature on modeling with stakeholders from the perspective of the need for transformative change. However the paper is more than just a literature review as it also incorporates insights from 23 semi-structured interviews with participatory and non-participatory modelers. It also develops a framework that allows us to distinguish modeling approaches as transformative and structures thinking about the role for modeling in processes in transformative change. Specifically, we identify ways in which model-building with stakeholders can be used to support the formulation of policy pathways. This focus complements the extensive literature om model-based design of policy pathways [3,21–24].

In line with [25,26], we argue that the model based design of policy pathways needs to take the form of a bidirectional exchange between those developing and running the models, and the stakeholders and decision makers who possess in-depth local knowledge about the system being modeled while interacting and negotiating on the basis of the models and their results. Something that has largely been overlooked by the existing literature on model-based support for the design of policy pathways.

The review identifies the different contributions of approaches for modeling with stakeholders in terms of theory, terminology, principles, and methodologies. The emphasis lies on collaborative approaches that can be characterized as 'transformative', i.e., supporting participants to formulate transformative policy pathways and action plans. Such a typology of approaches facilitates consultations between and systematic comparison of the different modeling approaches [16,18]. The typology is based on a literature review, supported by twenty-three semi-structured interviews with participatory and non-participatory modelers associated with the existing approaches.

The remainder of the paper is structured accordingly. In Section 2, the role of models in transformation and a conception of transformative change are explored. In Section 3, a typology of approaches to model building based on types of participation is offered. In Section 4, the types of approaches that support transformative change are compared. In Section 5 principles for developing transformative participatory modeling processes are formulated. Lastly, in Section 6 conclusions and recommendations are given.

2. Role of Models in Transformative Change

2.1. Transformative Change

Transformative efforts in coupled socio-technical-environmental systems require a shift towards a more sustainable pathway, which in turn requires a change of our social reality, its goals, paradigms or deep structures. This change shifts current ways of acting, raising ethical and procedural questions of what such a future looks like, how it can be brought about, and who has to power to create these shifts [1,27]. According to Mezirow, transformative learning is a "deep, structural shift in basic premises of thought, feelings, and actions" [28]. Transformation is mostly triggered through a personal or social crisis that poses a "disorienting dilemma" shaking individuals to their core [29]. It can also be brought about cumulatively through a process of learning which transforms meaning schemes of individuals and organizations [30]. Meaning schemes are defined by Mezirow as "the structure of cultural and psychological assumptions within which our past experience assimilates and transforms new experience" ([31], p. 21). The disorienting dilemma or cumulative events can set in motion a process of critical reflection upon beliefs, assumptions, and values that were challenged, requiring courage to then examine incoherent belief systems, meaning schemes, strategies, and premises. Critical reflection can be followed by the development of meaning perspectives that include explanations for the disruptive event and make thought more coherent as well as more complex. Finally, the new perspective is integrated in patterns of thought as it is translated into new patterns of action. A simplification of this process is shown in Figure 1. Disorienting experiences can thus provide windows of opportunity to reflect critically and transform our meaning perspectives, resulting in alternate patters of action that affect the structure of society and shift it onto alternative development pathways.

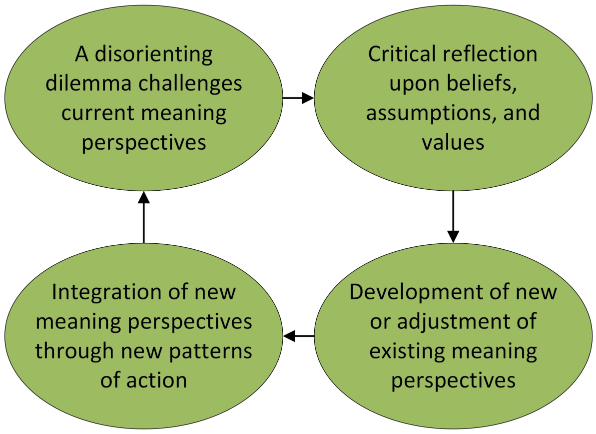

Figure 1. Simplification of process of Merzirow's transformative learning adapted from [32].

Collaboration in the face of systemic crises comes about by actors realizing that the status quo requires fundamental changes which cannot be brought about by individual actors. After the perspective transformation, discontent with current meaning perspectives can be related to problems others are facing and bring about a collaboration with others [28,33]. To establish collaborations between different actors requires the capacity to build bridges between actors in different projects that share discontent with current meaning perspectives [34]. In this process, there is no distinction between expert and stakeholder knowledge but instead includes knowledge from a wide variety of stakeholders with different knowledge domains ([35], p. 4). In transformative processes the traditional distinction between expert and stakeholder knowledge is "unhelpful and outdated", favoring a perspective that sees an expert in a wide variety of stakeholders with different knowledge domains ([35], p. 4). Conceptualizing transformation as a process of universal participation and the building of capacity in each participant, requires an ability to see a potential protagonist in each actor and human nature as not only self-interested but also capable and willing to contribute to a greater good through cooperation [36]. When different actors come together to transform a system under conditions of high uncertainty and decision stakes, multiple, potentially valid, knowledge frames come together, giving rise to ambiguity [37]. To design collaborative processes for development of policy pathways and action plans the relevant uncertainties must be identified and the legitimate interpretations understood [17].

Uncertainty can be classified in different types and levels, to help stakeholders to clarify their meaning and relevance [17,38]. Brun [39] distinguishes between useful and useless ambiguity in knowledge creation. Ambiguity resulting from the validity and reliability of information is not useful to innovation and should be minimized through additional research. Useful ambiguity results from multiplicity and novelty and is essential to innovation (cf. Ashby's law of requisite variety [40]). Useful ambiguity is approached through collaborative or social learning and including extended peer communities in decision making in ways that integrate multiple perspectives and make research accountable to the end-user [41,42]. The conversations and products that come out of extended peer communities such as models, papers, scenarios, policy pathways, and action plans, are subject to change and serve as temporary scaffolding until more definite theories and solutions can be offered. Such processes acknowledge that the map that is made by science to navigate reality in turn shapes this reality, making it important for members of the scientific community to continually reflect critically on their maps [43].

Learning about how to achieve transformation occurs in cycles of systematic learning that include (1) studying our observations, frameworks, and strategies as well as planning for action, (2) acting on this plan, and (3) reflecting from different levels on the results as well as the frameworks that guide action (see Figure 2 below).

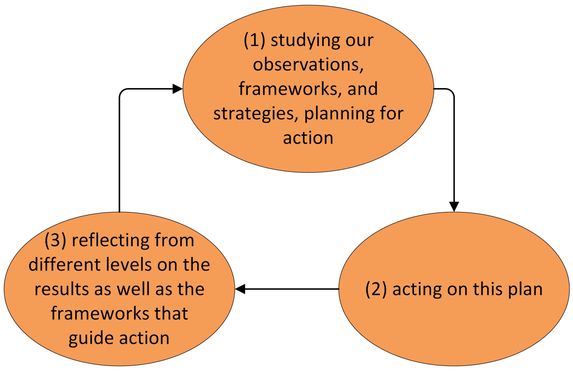

Figure 2. Cycles of systematic learning.

The shifting of systems towards alternative development pathways is not a linear process that can be planned exactly, but is characterized by continuous adaptation and evaluation [4,44]. Developing policies in pursuit of transformative change can be conceptualized as a pathway that is formulated upon exploration of possible pathways and co-evolves in response to a changing environment and continuous evaluation. The design of monitoring arrangements facilitating learning about pathways can be through policy-oriented learning, but close attention must be paid to whom monitors what and how to avoid overemphasis of monitoring the objectives of original actors at the expense of other actors that join later [45,46].

The transformative efforts aimed at changing the system's emergent development pathway, are deliberately undertaken by a variety of actors, involving different system components, under the pressure of external events or undesirable state spaces [27]. Transformative efforts make explicit the dimension of transformations which require a shift in current ways of acting, raising ethical and procedural questions of what such a future looks like and how it can be brought about as well as who has to power to create that future [1,27].

2.2. Role of Simulation Models

As we confront wicked problems from the perspective that the world is increasingly interconnected, tools are required that allow us to make sense of the resulting complexity. Such tools include development of "simplified, self-consistent versions of that world" to help us understand it [47]. Models are powerful tools to enhance and discipline our thinking about complex matters as simplified representations of reality. Models can take on various forms, such as mental models that exist in our minds, stock and flow diagrams, or computerized models based on differential equations or agents [48]. Models can play a role in the critical reflection phase of transformative learning, ensuring that in the process of reflection we rely not only on what Kahneman named "system 1 thinking" which is primarily intuitive thought processes based on personal values as well as emotions, but also on "system 2 thinking" that is slower, logical, and rational [18,49]. Computer simulations create a virtual world or testing ground that can aid the learning process without acting first in the real world [50] (see Figure 3).

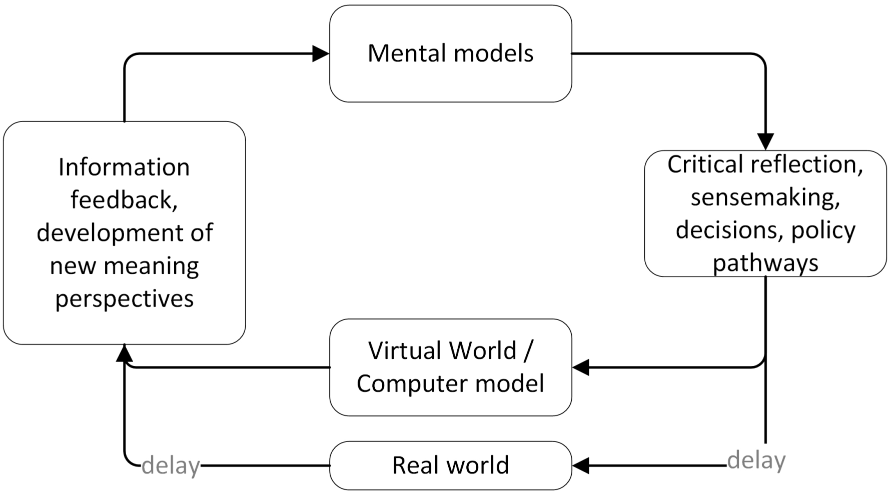

Figure 3. The process in which models support critical reflection and mental models, adapted from [50].

Simulation models can test mental models by exploring the consequences of the assumptions, provide an overview of possible future pathways for a transition, guide our behavior, and generate scientific knowledge. Models convey reality only to a limited extent and are highly dependent on the assumptions on which they are built. The limits and constraints of simulation models have to be clearly articulated if they are to be useful [12,19,51,52]. While models often form the base for environmental policies, the certainty conveyed by the hard numbers can lead to serious errors when they are discovered to be based on unrealistic or wrong assumptions [13].

In addition to their role in critical reflection, models also play an essential role in scientific practice and knowledge generation. In teams models allow knowledge sharing among members thus enabling members to build on that knowledge without requiring complete consensus on every part of the model. According to the theory of distributed cognition, knowledge generation relies on the use of inscriptions or artifacts such as tables or diagrams, that can be abstracted upon to make scientific knowledge explicit ([53], p. 316).

Simulation models offer higher-order inscriptions, or cascades of inscriptions that constitute a boundary object which helps to visualize complex and large bodies of information [54]. Boundary object theory explains how objects such as models can bring together diverse group of stakeholders around a simple object or artifact such as a visual representation or causal loop diagram [9,10]. The object represents the system's elements and their connections and is flexible to be changed by participants as they translate their tacit knowledge into explicit knowledge, shifting focus away from personal opinion to common understanding [55,56].

Leveraging the power of models in supporting critical reflection and acting as a boundary object in processes of social transformation requires two lines of action. The first is to enhance the level of insight models can yield by improving model building itself, the other is to improve participation in and around the model building. Models can assist in making our thoughts more coherent and as a boundary object bring together diverse groups of people to collectively make their thought and action more coherent, unite them in a common purpose, or solve a common problem. Models also allow a process of accompaniment by experienced people, that allow knowledge to spread and become incorporated in practice in a more effective way than by merely reading about them, for example, in a published modeling study [57]. The social process required to build models together, supports the process of transformative change. Thus, in its role in transformation, emphasis is put on the role of the model as a boundary object in complex situations and as a tool to generate feedback in a process of learning.

However, a transformative process requires a clear understanding of the function as well as limits of simulation modeling which are only simplified and generalized version of reality [13]. Ingrained myths that models can yield "objective evidence" or "straightforward policy solutions" for policy makers, especially when fed large amounts of data must be replaced by more coherent understanding of the nature of transformative processes and modeling with stakeholders ([58], p. 113). Rather than yielding direct results, modeling processes that support transformative change engage stakeholders in a process of learning and critical reflection not only on practical problems policy makers are faced with such as water scarcity in an area or setting the price of CO_2 emissions, but also the conceptual frameworks that shape current ways of thinking about those problems. The framing and conceptualization phases that precede the construction of simulation models play a fundamental role in the transformative process. The framing and conceptualization determines how a problem situation is translated into a problem formulation that is formal and abstract, allowing the problem to be further studied using simulation models or other decision-aiding methods [59].

A process should empower all participants to reflect critically on current system pathways and what aspects of the system structures need to be changed to steer the system unto alternative development pathways. Furthermore, the process must give insight into the ambiguities, uncertainties, and risks involved with exploring, formulating, and implementing development pathways in a process of social learning [17].

3. Typology of Approaches to Modeling with Stakeholders

In this section a typology is presented that classifies approaches that support 'transformative' change and aim to empower stakeholders to take ownership over their reality and formulate sustainable policy pathways [14–16]. The typology below is based on a literature review as well as the conceptual framework for transformative modeling set out in Section 2. Existing reviews outline the different approaches originating from diverse authors and disciplines including collaborative modeling, group model building, and knowledge co-creation. The literature that aims to structure the modeling with stakeholders processes is based on different factors including, seminal work of initiators [16], types of models used [60,61], disciplines from which they originate [62], modeling paradigms [60], literature reviews of a particular body of literature such as water management [63,64], the difference in interactions between the tools and participants [62], the level of stakeholder involvement in the process [63,65,66], the structure and evaluation of the participatory modeling process [19,67,68], diversity of actors involved [62], stages of the modeling process in which the stakeholders are involved [69], and the parts of the socio-technical-environmental system the model aims to represent [70]. This typology uses the insights from these reviews to identify the main approaches that are being used across disciplines, setting apart the approaches based on the interest in stakeholder involvement and identifies those that support transformative change and involve social learning that builds capacity in stakeholders.

Four general approaches to (simulation) modeling with stakeholders are identified based on the form of interest in stakeholder participation, namely nominal, instrumental, representative, and transformative approaches. Each approach has corresponding types of participation and types of stakeholder control over information flow in model building. The typology categorizes general approaches to model building with stakeholders which can be developed over time, not ways to evaluate and categorize specific modeling studies, for which other frameworks exist [67]. The typology is presented in Figure 4 and the section below explains the basis on which the categorizations is made.

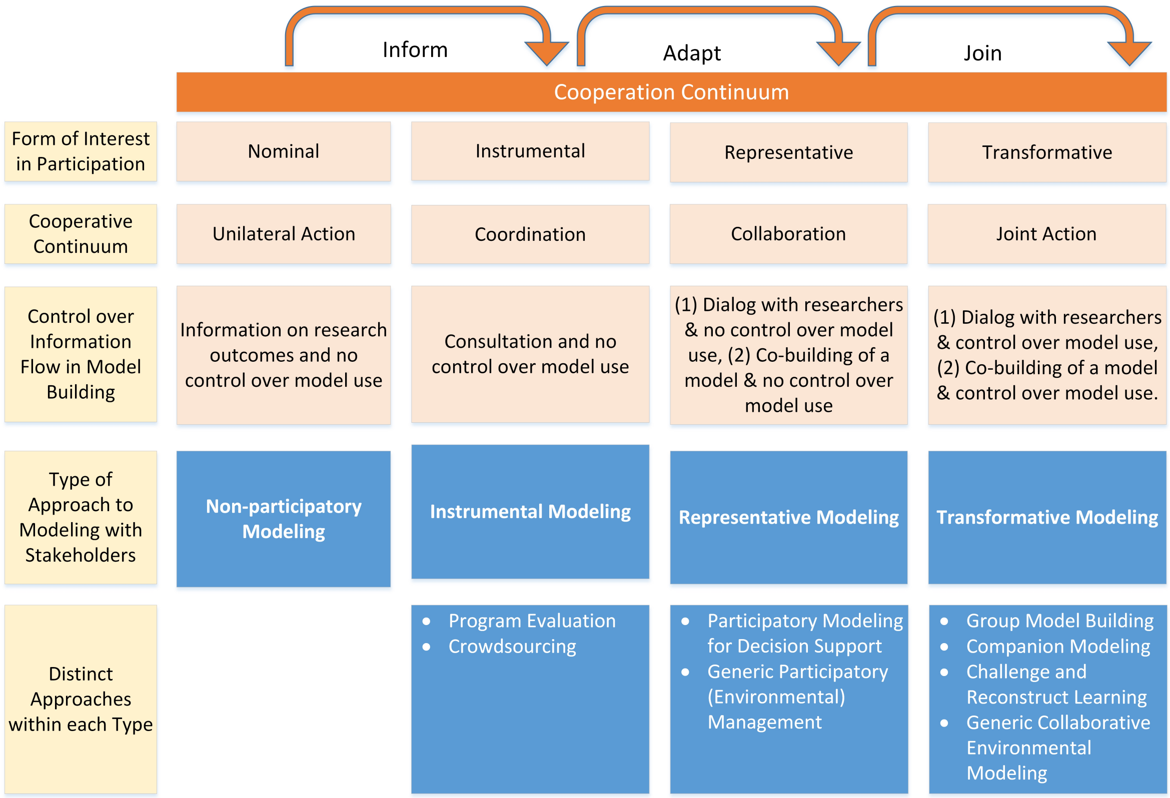

Figure 4. Typology of Approaches to Modeling with Stakeholders.

3.1. Continuum of Forms of Participation in Modeling

There are various ways to distinguish between levels or types of participation such as Arnstein's ladder [71], the wheel of empowerment, degrees, modes, or a continuum. The latter emphasizes cooperation as "non-directive, dynamic, and iterative" in nature ([72], p. 424). Whether a more integrated participation is desirable depends on the goals of the project as well as the available resources, skills, and capacities to engage in high forms of collaboration [18]. Interactions are dynamic and as part of a process or project various forms of participation can co-exist or change over time as the project takes on new goals or shapes. Lastly, the process is iterative as a project can be placed on different ends of the continuum at different times and advance along it as the result of prior cooperative achievements. Sadoff and Grey [72] developed a cooperative continuum with different benefits associated with forms of cooperation. The higher forms of cooperation have the benefit of creating symbiotic effects associated with transformation.

3.1.1. Interest in Participation

Distinguishing between different forms of interest in participation is a way of "drawing out the diversity of form, function, and interests within the catch-all term 'participation'" ([73], p. 7). Categorizing participation based on interest helps distinguish between projects in which participation is paid lip-service to or is used as a means to an end such as securing funding, pushing an agenda, or empowering stakeholders [74]. The different forms of interest in participation are summarized in Table 1, categorized according to (1) the top-down interest in the participation by those that design and implement the project, (2) the bottom-up interest of those that consider themselves participants in the project, and (3) the function of participation in the project.

Table 1. Interests in Participation adapted from [73].

Form	Top-down	Bottom-Up	Function
Nominal	Legitimation	Inclusion	Display
Instrumental	Efficiency	Cost	Means
Representative	Sustainability	Leverage	Voice
Transformative	Empowerment	Empowerment	Value (means/end)

Nominal participation increases a project's legitimacy by including stakeholders in spreading the results of the study. Instrumental participation uses participants to increase efficiency and reduce costs. Representative interest ensures participants agree to the solution by ensuring their wishes and concerns are heard. Finally, a transformative interest in participation does not see participation as a means to an end, but as both the means to obtain benefits as well as an end in itself. Even though this type of participation is initiated from the bottom-up or by participants themselves, the top or those that design and implement the project also have a genuine interest in participation as having value in itself and work to enable such participation.

A transformative participatory project engages participants in a continuous, dynamic exploration of reality, which "transforms people's reality and their sense of it", empowering them to take ownership of it ([73], p. 9). Participation in empowering transformative projects therefore constitutes an ideological commitment and cannot be merely reduced to the benefits that the collaboration is expected to generate, but may not always attain [18,75,76].

3.1.2. Control over Information Flow

The form of interest in participation corresponds to the level of the stakeholder control over the information flow. Barreteau [74] visualized control over the information flow as occurring between four nodes of the stakeholders, policymakers, researchers, and models or the representation of the system used as a boundary object. In non-participatory processes, no dialogue occurs. In instrumental participatory processes consultation occurs, but the participants have no control over model use. In representative forms of participation, dialogue with researchers about the model and the co-building of the model occurs, but the participants have no say in the model use. In transformative modeling process, the model is constructed either in dialogue with researchers or through the co-building of a model and the participants retain control over the use of the model after it is constructed. Whether there is a difference between building a model in dialogue with researchers or co-building the model for the transformative effect, remains an area of learning.

3.1.3. Role of Participation in Transformative Processes

All forms of participation in model building have a role to play in transformative processes and in the empowerment of stakeholders.

The *non-participatory modeling* projects with nominal forms of participation have an agenda setting function, offering knowledge, analysis as well as challenges. They advance discourses in science and society, such as the Club of Rome's Limits to Growth study [77].

Instrumental modeling uses stakeholders instrumentally to gather more information concerning problems that are structured or semi-structured and include forms of crowd sourcing and program evaluation.

Representative modeling aims to give stakeholder a voice so that the stakeholders at the bottom buy into the outcome and those at the top can ensure their decision is sustainable ([73], p. 9). While the benefit of involving stakeholders in this way is often assumed, it has not been empirically validated. Some correlation between acceptability and the use of the model has been described [16,18].

The participation in *transformative modeling* does not merely serve a benefit, purpose, or interest, but is a posture or mode of operation. This type of modeling is governed by a conceptual framework that has different conceptualizations of power, expert knowledge, capacity of stakeholders to contribute, and the nature of science. It thus requires the twofold process of advancing our model building capacity as well as continuously building capacity in individuals, communities, and institutions to generate, apply, and propagate knowledge within an evolving framework.

3.2. Four Approaches to Modeling for Transformative Change

Within the literature on transformative modeling, four distinct approaches for modeling with stakeholders are identified, namely

- Group model building
- Companion modeling
- Challenge-and-Reconstruct Learning
- Generic collaborative (environmental) modeling

Exploring their differences and similarities does not determine whether one approach is better than the other, but serves to identify interest areas of the modeling community [78]. Each approach can be further developed as a distinct approach, while learning between approaches about aims they have in common such as the genuine interest to involve stakeholders can be shared.

Group model building originated in the 1980s and was first used by a group led by Jacques Vennix in the Netherlands, and was further collaboratively developed in the United States at the University at Albany by George Richardson and David Andersen [79]. Group Model Building is the first approach in the field that systematically studied the effect of stakeholder involvement and its effects on model buy-in, consensus in decision-making, and heightening motivation to turn insight into concrete action [80]. There is a general assumption in the modeling with stakeholders community that group model building is uniquely associated with system dynamics models and in the business context as it originated as such. However, it can also be used with agent-based models and other modeling paradigms. There are examples in the literature of combined group model building with agent-based modeling, geographic information system, social network simulations, concept models, nutrient modeling, and combinations of those [81,82]. Especially the more recent contributions such as ScriptsMap and essential team roles, developed in the field of business and management, are eminently transferable. Finally, Community-Based System Dynamics modeling and mediated modeling also fall under Group Model Building approaches as they draw on similar concepts and methodologies [83,84].

Companion Modeling, also known as ComMod, is another version of group model building that originates in the 1990s with a group of researchers from the Agricultural Research for Development Agency (CIRAD) in France [85]. Companion modeling combines the construction of agent-based models to make reality intelligible as a well-suited "metaphor of reality" with role-playing games and other tools which provide hands-on learning to explore predominantly environmental issues [86]. Key to companion modeling is accompaniment or the idea that the modeler figuratively walks together with stakeholders to gain more knowledge or improve decision-making. Companion modelers emphasize that their approach is best understood as a "scientific posture" or moral stance rather than as a methodology that can be exactly laid out in a book [85]. However, companion modeling processes do not have "transformation" or making changes as their explicit objective, but they hope to aid this process by the enhancing knowledge of how the system works and accompanying the decision-making process (Barreteau, personal communication, 9 March 2017).

The Challenge-and-Reconstruct Learning (ChaRL) approach was developed by Smajgl and Ward of the Mekong Region Futures Institute to connect science and applied research with sustainable development policy decisions and pathways [87]. The approach consists of five steps of a learning process in which assumptions or heuristics underlying the matter at hand are formally questioned, measured and reconstructed through a structured set of workshops going through (1) scoping, (2) qualitative scenarios, (3) eliciting beliefs, (4) challenging beliefs elicited with scientific evidence and models, and (5) formulating an action plan [87].

The generic collaborative (environmental) modeling approach has a generic framework outlining the stages that modeling with stakeholders goes through while retaining the flexibility of the exact design of the process, mostly in the context of sustainability questions [19]. The framework distinguishes between two switches in the process, one between the "soft", conceptual, qualitative phase of the modeling in which the problem and its context are identified, and the "hard" quantitative phase of the model construction, and again back to the "soft" qualitative part of result interpretation and translation into policy.

4. Comparing Approaches to Modeling for Transformative Change

A few key differences and similarities among the approaches stand out ([65], p. 757). From interviews across the approaches, it became clear that modelers are themselves sometimes unclear about what distinct yet similar approaches to transformative modeling exist or how they can be used. Table 2 presents a detailed comparison between the approaches. We will discuss in detail the key differences in:

- the knowledge elicitation tools
- the types of models
- posture of the facilitator and power balance
- guidance, standards, and templates
- reporting

Most approaches rely on a specific set of knowledge *elicitation tools* that emphasize a specific mode of learning. For example, stock-flow diagrams for Group Model Building to map system feedback loops, visions and scenarios for Challenge-and-Reconstruct Learning to create a normative benchmark for decisions based on models, and role-playing games for Companion Modeling to learn by doing. Each approach has its own rationale and systematic practicing and comparison of the techniques is required to gain more insight as to what is more effective in what context. A combination of approaches such as role-playing games and vision building is also useful if time and resources allow.

Not all *types of models* are suited to involving stakeholders, as some require high levels of expertise to build. Involving stakeholders in model construction is a consideration that is made based on the expertise needed to build the model, current expertise of the stakeholder as well as the time and resources available for this part of the process. Lastly, some modeling typologies are based on the modeling paradigm employed. For models that support transformative change processes, the most important question to ask is what the purpose of the modeling is and what type of data is available after which any paradigm can be employed. Some models are better at showing the individual dynamics and others at showing the overall dynamics. These limitations can also be overcome by developing hybrid models.

The *posture of the facilitator* and the role of the facilitator in the team are divided differently across approaches. The group model builders and companion modelers have clearly defined the different required roles, group model building with a designated facilitator and person to mediate between science and the participatory process, while companion modeling does not. Across the approaches the conception of facilitation is different; from the facilitator as a ″know-it-all″ to a facilitator not even being required, since participation should occurs on an equal basis [88]. Facilitation can thus also be thought about as an attitude or posture that is taken especially by the modeler, developing rapport with the participants with a helping, inquiring, profoundly curious, integer, and authentic posture. Cultivating a facilitative attitude goes hand in hand with reconceptualizing power as something that does not lie with one dominant facilitator or researcher, but lies also in its collaborative, unifying nature. Companion modelers have made this issue most explicit, including an analysis of *power balance* and legitimacy that researchers should make explicit. While the literature for all approaches acknowledges this challenge, few approaches have systematically built checks and balances in their processes to account for power imbalances. One of the main ways to account for power imbalances is also to think carefully about whom to invite to the meeting and where to hold it [63,89]. Overall, cultivating facilitating and collaborative attitudes may take time, especially for those model builders that come from more technical or software backgrounds and may not have had training in soft skills required for facilitation.

The extent to which the models can provide unique process *guidance, standards, and templates* also differs. There is a tension between the extent to which preparation, execution, and evaluation of the participatory modeling process can be structured and the extent to which it should stay flexible. Standardized guidance helps advance the modelers with stakeholders field and opens what is sometimes seen as the 'black box' of participatory processes and helps scientists to make systematic comparisons. Group model builders [90] have a framework that makes comparisons possible, focusing on context and mechanisms, so the learning effect can still be further investigated. Companion modelers have developed the Monfavet canvas for ex post reflection and the Canberra Protocol for documenting findings and keeping individual logbooks ([86], p. 319). Challenge-and-Reconstruct learning has a distinct number of steps which facilitates the use of ex ante tools such as a psychometric evaluation that can see the change of beliefs in participation as a result of the modeling exercise [91]. However, this only enables the monitoring of shifts in individual belief, not those of the group as a whole [92]. While there is a tension between the need to structure as well as remain flexible when designing approaches, all approaches agree that the inclusion of stakeholders should proceed in a structured way, be taken seriously, and thus be planned beforehand either through a generic framework, specific steps, or a conceptual framework.

Reporting is not only useful for systematic evaluation, but also to transfer the modeling approach to other modelers, policy makers, and stakeholders alike. This can be through face-to-face classes and professional training at universities and institutes as well as training participants so that they can execute the process themselves. Transferring the approach and the tools requires a large and interdisciplinary skill set that includes conflict resolution, communication in varied settings, report writing, and multi-actor simulation skills. Even if the accompaniment is of a high level and quality, participants rarely gain the ability to continue the process autonomously, creating another area of learning. Transferring the approach through personal communication might in some cases be more effective than reading handbooks, as the accompaniment is stronger. Yet handbooks can also provide insights and help to practitioners to learn from what is already out there. The question should be to what extent a transfer of the approach is desired. Should participants be able to build their own models, or should they be able to understand the model and learn when it is useful to undertake collective modeling exercises so that documentation does not become an end in itself? Table 2 below gives an overview of the comparison of approaches to transformative modeling.

Table 2. Overview table of the comparison of approaches to transformative modeling.

	Group Model Building	**Companion Modeling**	**Challenge-and-Reconstruct Learning**	**Generic Collaborative Environmental Model Building**
Founders	Richardson, Andersen, Vennix, Rouwette. CBSD: Hovmand	Barreteau, Bosquet, with a group of scientists at CIRAD, France	Smajgl and Ward	Various. First systematic overview by Voinov and Bousquet [16]
Country and Year of Origin	US (Albany) and the Netherlands (Nijmegen), 1980	France, 1996	Mekong Area and Australia, 2000	Predominantly Universities in the US and Europe, 2000
Disciplines in which it developed	Operations Research, System Dynamics, Business	Software engineering, environmental science	Environmental science	Environmental science
Research Community	System dynamics community	Companion modeling network, environmental scientists and researchers, anyone can subscribe to the charter	Natural Resource Management, sustainability	Environmental scientists and researchers
Number of Papers in Scopus in March 2017 and Search Term Used	154 (“Group model* building*”)	207 (“companion model*”)	2 (“Challenge-and-Reconstruct Learning”)	569 (“participatory* model*”)
Main Journals	System Dynamics and review	Environmental Modeling and Software, JASSS	Environmental Modeling and Software	Environmental Modeling and Software, Ecology and Society
Knowledge Elicitation Tools	Qualitative stock-flow diagrams, causal loop diagrams	Role-playing games or participatory simulations	Exploratory scenarios and visions, survey, and study to elicit facts	Decided on a case-by-case basis
Theoretical Framework	Boundary/intermediary object (Black 2013). CBSD: Marilyn Frye, Cressida Heyes, and Bill Lawson, Paulo Freire	Complex adaptive systems, Post-Normal science, Kolb’s experiential learning cycle, enactment theory, constructivism	Theory of Planned Behavior, cognitive theories of Schwartz and Stern et al., Image theory, Habermas rational reconstruction	Not clearly articulated
Roles Assigned	Group model building roles: modeler facilitators, modelers, reflectors, recorders, note takers, photographers, community facilitators	Lay person, researcher, technician, institutional, Commodian, student	Includes: modelers, trained observers through a specific, interactive and consistent protocol, decision makers, researchers	Not specifically defined but includes: facilitators, decision-makers, modelers, researchers

Table 2. *Cont.*

	Group Model Building	Companion Modeling	Challenge-and-Reconstruct Learning	Generic Collaborative Environmental Model Building
Facilitation/modeler	Facilitative Attitude, LERT principle, high dependence of process on facilitators hypothesized but not proven	Accompaniment, Companion modeling posture	Not conceptually or systematically addressed	Acknowledged as important but not conceptually or systematically addressed
Purpose of Models	Virtual worlds in which decisions can be tested	To reflect decision dynamics of stakeholders	As alternative beliefs, scientific evidence, never to represent stakeholder beliefs	Various
Modeling Paradigm	Mainly System Dynamics	Mainly Agent Based Models	Various; hydrological, integrated agent-based models, geographic information system	Various: coupled component, Bayesian, ABM, SD, hydrological, watershed, geographic information system
Relationships of Power	Addressed especially in DBSD	Systematically addressed in the literature	Mentioned but not systematically addressed in the literature	Mentioned but not systematically addressed in the literature
Framework to compare individual cases	Evaluation [90]	Canberra Protocol [86] , ADD-ComMod project	COPP [67]	Various [60–63,70,76,93–95]
Training in the Methodology	Courses at Radboud university Nijmegen	Listed on website. Courses in French University.	Contact Merfi institute, not widely available	Various
Methodology Publicly Accessible	http://tools.systemdynamics.org/web-based/	Open, literature widely available. http://www.commod.org	Academic papers available, practical facilitation handbook not. https://www.merfi.org/	Calls for creating a database and developing a good practice guide [18]
Framework to systematize process	Scripts and ScriptsMap	Logbooks, Montfavet canvas, ARDI (Actors, Resources, Dynamics, and Interactions)	N.A.	Generic step-by-step framework

5. Developing Transformative Participatory Modeling Processes

There is not one ideal way to conduct participatory processes to support the transformative change and the formulation of policy pathways. It is, however, possible to articulate a set of principles and a common language or conceptual framework that underlies such processes. This posture as well its ethical principles and conceptual framework has been formulated in a charter which can be a starter for further conversation [85]. Success can be documented and a sequence of process elements repeated and studied over time. The differences between the approaches, mainly in the tools they use to elicit knowledge from their stakeholders, the way they divide team roles, provide unique guidance to structure the participation as well as the extent to which they have formalized practices that record and reflect upon those experiences, the purpose of model building, and what they have learned about capacity building and power dynamics should be explored systematically. The practice of transformative modeling benefits from clear and open documentation that is accessible to researchers, NGOs, decision-makers, and stakeholders that might be interested in a participatory process. The documentation should include both the modeling approach as well as the design for the stakeholder process and potentially the nature of the conversations that were held with participants prior to the modeling process.

An important insight from the literature review, that together with the interview forms the basis for this article, is that transformative modeling does not need new approaches, but rather a clear articulation of similarities and differences of current approaches as well as set of principles and a framework or roadmap that unifies existing approaches sharing the same goal; to empower a group of stakeholders to shift their systems onto alternative development pathways in the face of collapse. Transformative modeling is not attempted lightly: it requires a systematic and structured effort by a core team of people that have model building capacity as well as community building skills. Institutions such as research facilities, local government, and others set the boundary conditions for the process, allowing participants to engage in the process of social learning. Systematically developing approaches to modeling with stakeholders should also include reflection on what motivates stakeholders to get as well as stay involved and ultimately become protagonists of transformation, involving others on the path.

For modeling exercises to play a role in transformation, those involved must learn to *critically analyze the environment* in which participants operate and the dominant meaning schemes they use. The environment influences both the policy pathways and action plans available to them as well as the conceptualizations and assumptions the participants hold. For example, it is difficult to develop collaborative, cross-disciplinary processes in environments that do not themselves have a culture that has already some characteristics of a cooperative environment. The current mono-disciplinary approach to science and "winner takes all" economic and social reality make this extra challenging. The checks and balances needed to overcome power asymmetries in the modeling process require systematic attention. Each modeling activity is to be an *enabling experience* which helps participants build capacity for transformation by developing further the qualities, attitudes, capabilities, and skills of a new type of social actor whose energies are entirely directed towards sustainable development [42]. The motivation of all in the process, both those initiating and participating, share a commitment to empowerment of all involved in a common process of learning. Finally, such a process of inclusion should have the power to bring about *shared commitment to action* and move the system unto desired development pathways.

6. Conclusions

As human beings, we can never achieve perfect certainty, objectivity, or choose the perfect policy pathway. We can, however, come together and improve our collective reasoning and knowledge through consultative and collaborative processes. In these processes we exchange opinions and judgments and explore, formulate, implement, and evaluate policy pathways and action plans collaboratively. Models, being boundary object around which stakeholders can gather and interact without requiring consensus, support this complex process of carving out development pathways. The stakeholders are equal collaborators in a process of generating knowledge that occurs both inside and outside the figurative laboratory or university. Simulation model building with stakeholders can provide a learning site to uncover participant motivations and ways to empower them.

The literature on model-based design of policy pathways has hitherto strongly focused on how model-based scenario techniques can be used to inform pathway design. Although it has been acknowledged that stakeholder involvement is crucial and that one should foster a process of deliberation with analysis, limited attention has been given to how to realize model-based exploration and design of policy pathways with stakeholders. The field of modeling with stakeholders is fragmented across disciplinary fields and academic "not invented here syndrome", hindering its development. The differentiation between the approaches can be understood as resulting from different modeling technology that evolved from system dynamics to complex coupled multi-models with the increase of computational power as well as the development of the approaches within their own disciplines, research communities, and journals. The good news is that interviews revealed a openness to learning more about other approaches, combining and integrating them. To alleviate this problem and facilitate this learning and integration, we presented a systematic review, developed a typology that makes comparison possible and easy, and provided a set of general principles that can guide a transformative participatory modeling effort.

Just as the various approaches for modeling with stakeholders require researchers, decision-makers, and stakeholders to develop new kinds of capacity and relationships, developing processes for fostering transformative change requires new, post-normal ways of practicing science. The conceptualization of transformative change and the frameworks within which policy pathways are carved out, are themselves unclear. To tell more coherent stories of how we shift our systems onto alternative development pathways, social science needs to gain a richer, more coherent understanding of individual and group behavior, communication between disciplines, languages, and cultures, sacrificing personal interest to bring about the advancements of the whole. Such a conceptualization occurs against the background of an understanding of what science, objectivity, subjectivity, and rationality are. This article offered the outlines of a conceptualization of transformative change, but requires development by engaging in the practice of modeling with stakeholders with a twofold purpose; modelers reflecting on their own practices, continuously trying to improve it and strive for excellence, as well as collaborating and exchanging insights with others and putting practices into action to contribute to transformative change.

As science is learning to incorporate solution-oriented knowledge through collaborative processes, it will have to find structures that stimulate interdisciplinary research and collaborative processes that have their goals emerge from collaboration. This requires that the institutions surrounding the modeling exercises also start to take an interest in the empowerment of stakeholders and adopt participation as a posture. Governmental organizations and those involved with formulating policy pathways are uniquely positioned to convene a diverse group of people together to think through salient issues and to stimulate the development of model building that supports transformative change. The policy makers, in collaboration with scientists and stakeholders, can draw upon the different approaches to model-based support for different aspects of the process ranging from exploration and design to the implementation and monitoring of policy pathways. To evaluate whether approaches for model-based support actually can enable transformative change, the interest in participation from both those initiating and participating can be evaluated as well as the level of control over model use. Those involved must realize that participation develops along a continuum and can evolve over time; not all collaboration will automatically lead to symbiotic effects and reducing uncertainty usually associated with social learning processes.

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