Participatory modelling: A review of applications in energy whole-systems modelling to support decision making

Catherine Bale c.s.e.bale@leeds.ac.uk
School of Chemical and Process Engineering and School of Earth and Environment, University of Leeds, Leeds, LS2 9JT

1. Introduction

In this paper a brief review of participatory modelling (PM) methods is presented, and the methods are discussed in relation to application in whole-system energy modelling that supports decision-making. Broadly, participatory modelling is the method of incorporating stakeholders, including decision-makers at different scales, into the modelling process. Throughout this paper we make the distinction between whole-systems energy modellers residing in the academic community, and stakeholders involved in decision-making (policy-makers, planners, engineers etc.), though of course models are also developed and used by stakeholders, and academics are themselves stakeholders in energy systems.

There are many stakeholders in the energy system, and a different set will be needed for looking at energy systems at different scales (e.g. urban vs international) and for different purposes (e.g. understanding consumer behaviours vs centralised planning). Participatory modelling integrates the different views and representations of a complex system held by different stakeholders, collectively building a common model that can be used to co-generate solutions (or decisions) (Jones et al., 2009). Stakeholders provide different knowledge (often they are the experts and hold specialised knowledge that academic modellers do not), and modellers can often provide new modelling methods (e.g. agent-based modelling) and a theoretical contribution to model building.

The objectives of participatory modelling in general are to:

- Increase and share knowledge of a system, and,
- Identify and clarify the impacts of solutions to a given problem usually related to supporting decision making, policy, regulation or management (Voinov and Bousquet, 2010).

Though these objectives are often synergistic, in this work we are interested in the role of PM in supporting decision-making at different scales in the energy system. In this case we look at engaging stakeholders in the modelling process through participatory modelling as a means of informing decision making at different scales.

2. Participatory Methods

2.1 Review

There are numerous participatory methods, originating from different fields and research groups (Voinov and Bousquet, 2010), and there has been increased interest in these methods over recent years (Olabisi). Participatory modelling is a generic term, and includes: group model building (GMB), mediated modelling (MM), companion modelling (CM), participatory simulation (PS), and shared vision planning (SVP). Definitions of each are given in table 1, which is based on a comprehensive review paper by Voinov and Bousquet (2010). Collaborative modelling is another term often applied to these types of approaches, and may be used to refer to processes where the level of engagement is deeper (e.g. co-designing a model) (Basco-Carrera et al., 2017).

Though not of central interest here, other participatory methods may include an element of modelling (though modelling is not fundamental to the process) - for example, participatory action research and participatory decision analysis. Collaborative learning is also often used alongside

participatory use of models. Here we are interested in those methodological approaches that unite participatory methods with modelling tools.

2.2 Modelling tools

Among the tools most frequently used in combination with participatory methods are: system dynamics (e.g. causal loop diagrams, Vensim), Bayesian belief networks, fuzzy cognitive mapping (e.g. FCmapper), and agent-based modelling (e.g. Netlogo). In theory, any model could be developed with engagement from stakeholders as long as it was also able to be used (and shaped or edited in some way) by stakeholders. Systems dynamics modelling has the longest history of being coupled with participatory methods, but use of other modelling tools is expanding.

2.3. Overall approach

In participatory modelling, unlike in traditional modelling, the process is the focus rather than the end product (the model) or the knowledge generated (the results, scenarios etc.). The different stages of the process can be seen in Figure 1.

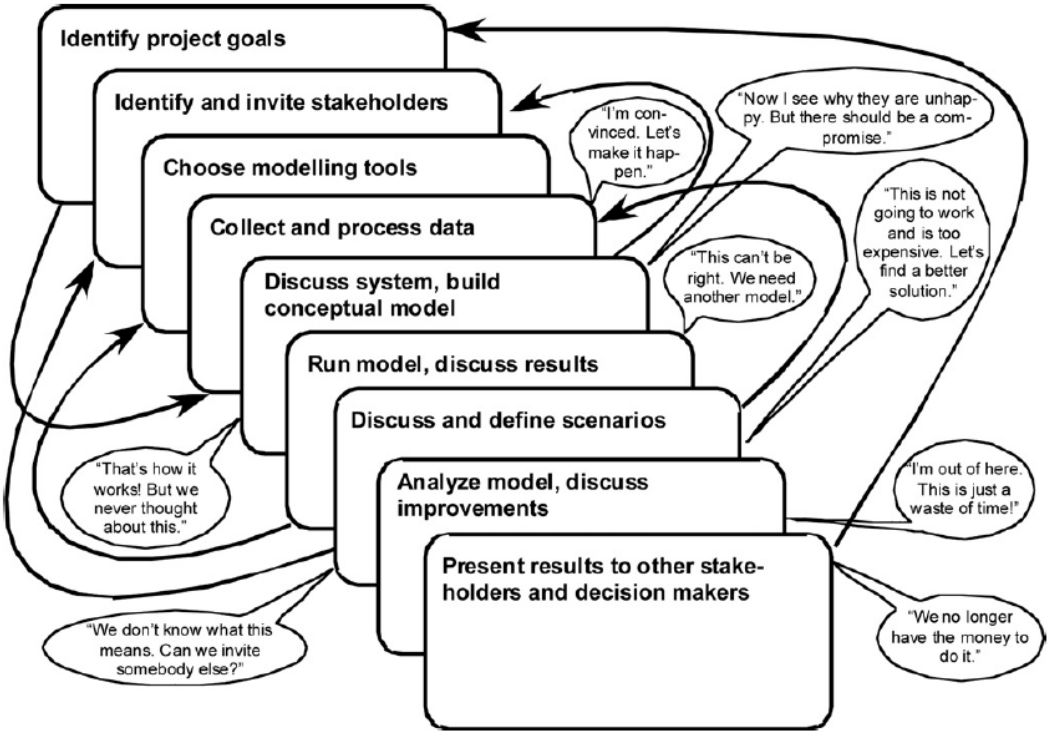

Figure 1 — Taken from (Voinov and Bousquet, 2010): Different stages of the participatory modelling process.

2.4 Benefits of PM in decision-making

In natural resource management and other environmental domains, participatory modelling methods are increasingly being recognised as an effective way to assist collective decision-making (Jones et al., 2009). Aside from decision making, there are several other expected benefits from developing a participatory approach including (adapted from Jones et al., (2009) and (Sandker et al., 2010)):

- Reducing conflict
- Improving the legitimacy of a model
- Informing collective action
- Enhancing learning
- Gaining a common understanding of a complex system

- Enhancing out-of-discipline thinking
- Investigating interventions in a controlled environment
- Formulating strategy and policy.

It is very difficult to evaluate whether a participatory modelling process contributes to better decisions, often because of the time-lags involved, the complexity of the system, and the number of decision-makers involved. In addition, decision-makers may have divergent motivations, and it may be helpful to recognise these rather than reach a consensus; in this case other methods may be more useful (Burgess et al., 2007).

Evaluation needs, therefore, to be conducted throughout the process, rather than considered at the end of the project. Jones et al. (2009), have set out a framework to evaluate the quality of the decision-making process from the perspective of the project team and participants. By applying this framework these authors have shown that through the participatory process modellers are better able to articulate their assumptions, and participants are better able to articulate their experiences. In another study, an on-going evaluation of participatory research was able to show that changes in belief influenced actual decision making (Smajgl and Ward, 2015).

2.5 Limitations

There are of course limitations to participatory modelling, not least the increased time, resource (for both modellers and participants) and, therefore, expense of the process. Other factors include the complexity of the models themselves, which need to be simple and user-friendly enough to be used by practitioners, and the fact that the model may be too narrow, e.g. “a multi-dimensional discussion turned into a model with a one-track mind” (Sandker et al., 2010). As discussed in the previous section, it is very difficult to show that the process would change beliefs, rather than “constructing unequivocal justification for policy decisions” that were already favoured (Burgess et al., 2007).

2.6 Good practice

Given the limitations outlined in the last section, the process of participatory modelling could be more risky than traditional modelling, as a result of the lengthy (and potentially expensive) engagement process, the unpredictable modelling development, and the fact that the process may be hard to replicate or may not produce generalizable results (though arguably this could be said of non-participatory methods also). There are, however, some good-practice guidelines to ensure projects are successful (taken from (Voinov and Gaddis, 2008)):

1. Identify a clear problem and lead stakeholders
2. Engage stakeholders as early and often as possible
3. Create an appropriately representative working group
4. Gain trust and establish neutrality as a scientist
5. Know your stakeholders and acknowledge conflict
6. Select appropriate modelling tools to answer questions that are clearly identified
7. Gain acceptance of modelling methodology before presenting model results
8. Incorporate all forms of stakeholder knowledge
9. Engage stakeholders in discussions regarding uncertainty
10. Develop scenarios that are both politically feasible and most effective

11. Interpret results in conjunction with stakeholders, facilitate development of new policy and management ideas, and engage stakeholders in reporting results

12. Treat the model as a process.

Garrod and co-authors (2013) also set out helpful considerations for stakeholder identification and interactions, as well as developing scenarios from the model. They show that through this process, coupled with development of a microsimulation model, “participants were receptive to both the concept of modelling and the use of models as decision-support tools”.

3. Use of participatory modelling in energy systems modelling

There have been few examples of formal participatory modelling applied to energy systems. Most of the applications of PM to date have been in understanding socio-ecological or environmental systems. A search was undertaken for literature on energy system models that have been developed using a formal participatory modelling approach using the following search terms in Google Scholar:

“energy system* model*” AND "group model building"	“energy system*” AND "group model building"
“energy system* model*” AND "mediated modeling"	“energy system*” AND "mediated modeling"
“energy system* model*” AND "companion modeling"	“energy system*” AND "participatory simulation"
“energy system* model*” AND "participatory simulation"	“energy system*” AND "companion modeling"
“energy system* model*” AND "shared vision planning"	“energy system*” AND "shared vision planning"

In total, 178 articles were returned in these searches (though this does not account for duplication, so the actual number of articles would be much lower). These articles were filtered to look for application of these methods to energy systems (rather than, for example, to one aspect, e.g. uptake of one energy technology), and remove articles that reference PM methods as an option but do not apply them (much more frequent), or cite other work on modelling. Only a handful of examples were found, and one example for each type of modelling is described here. No examples related to energy were found for mediated modelling or participatory simulation.

There are likely to be many models that have informally engaged with stakeholders throughout the model development, in data collection or scoping for example, though this is rarely well documented. Because these informal approaches are not built into the modelling process itself, the benefits of formal participatory modelling are unlikely to be realised. The other difficulty in finding papers that apply PM approaches is that often many different terms (aside from the formal definitions given in this paper) are used to describe the methods used, so there may be many more applications of approaches that might be considered PM but are not named as such.

The following sections present examples of participatory modelling methods applied to energy questions. One thing to note is that often combinations of distinct PM methods are used, or adjustments (such as different modelling software) are made to the methods reviewed here. There is commonly no ‘standard’ methodology for participatory modelling, but the main objectives of the approach are maintained.

An excellent example of a broad non-specific participatory modelling approach can be seen in the paper by Maallemi and Malekpour (2017), which details their approach to exploring long-term energy transitions. They respond to calls often levelled at whole-systems models to address

challenges, such as simplifying underlying social process, and incorporating uncertainty and different actors. They do, however, note that the limitation still remains of capturing transition characteristics in models by representing qualitative assumptions in quantitative parameters, and the usual problems of model validation and modeller subjectivity are not wholly removed through a PM process.

3.1 Group model building

To assist regional decision-makers in designing a future vision of Minnesota to 2050, a participatory systems dynamics modelling (otherwise know as group model building) and scenario visioning methodology was developed and applied in a collaborative manner (Schmitt Olabisi et al., 2010). The two techniques were used together to support the community in decisions about natural resource use, and the energy sub-system was represented in the whole-systems view of the city (that also included population growth and land and water use), with the aim of building systemic understanding and facilitating strategic planning. Here the authors define participatory scenario visioning as a process in which "decision makers with a stake in the outcome of the project are involved in crafting the scenarios", and we can consider this to be similar to SVP. Undoubtedly this is process often used in energy research, though not necessarily formalised.

In terms of limitations, the Minnesota project highlighted that, because of the lengthy process, this type of modelling is only appropriate for strategic long-term decision-making, and a defined decision outcome might not be possible. They also note tensions between the imaginative thinking that the scenario visioning brings, and the quantitative analysis that the systems dynamics modelling provides, that both impacted on the plausibility of visions. However, the dual approach means that consideration of both qualitative and quantitative information is encouraged, and fosters systemic thinking.

3.2 Companion modelling

Researchers at Leeds used companion modelling to develop an agent-based model to investigate the emergence of district heating networks in cities (Busch et al., 2017). The decision processes and actor heuristics that formed the conceptual framework of the model were developed collaboratively with stakeholders, and the model was also actively used by stakeholders to explore policy interventions. Details of the model (and ODD (overview, design concepts and details) protocol) can be found in Busch et al (2017).

The participatory companion modelling process had two phases consisting of two stakeholder workshops where a decision theatre methodology (Walsh et al., 2013, Bale et al., 2016) was applied. The purpose of the first workshop was to validate a conceptual model of the timeline of actions of actors who may instigate heat networks (local authorities, community energy groups, or private sector developers), and to identify barriers faced and capabilities needed. Following development of an operational model in NetLogo, the second workshop allowed the stakeholders themselves to use the model to explore scenarios and identify policy options that might enable development of heat networks by different actors. This resulted not only in investigating and considering scenarios for policy options, but perhaps more importantly, a systemic understanding of the decision process.

A number of benefits of this methodology were identified which support a whole-systems approach to decision-making, including recognising that infrastructure decisions are iterative (not isolated), that there are social and political, as well as techno-economic constraints, and that the possible interventions need to be systemic and are likely to encompass policy portfolios that target different stages and different actors in the system.

3.3 Shared vision planning

In work by Krzywoszynska et al. (2016) an interdisciplinary group of academics and stakeholders co-produced bottom-up visions of local energy systems using a numerical model (covering local electricity generation and demand) and a physical model to illustrate visions of the town of Stocksbridge. The two models were developed with stakeholders with the aim of enhancing social learning.

The authors here attempted some evaluation of the impact of the models themselves. They noted that the numerical model had a limited effect; the results did not provoke discussion and were either not incorporated into future work or were rejected. One participant did use the results of this model to "sell an idea", thus falling into the trap identified by Burgess et al. (2007) of justifying preconceived ideas. They also assessed whether through the social learning process participants had a change in understanding and found that there was evidence of 'factual' social learning. While the numerical model may not have been directly used, it was deemed by the participants as important for providing information, while interaction between participants helped give a sense of what might practically work.

One of the positive outcomes was the creation of new relationships between academics and stakeholders, and the growth of social capital.

4. Future directions

From the results of this review it is fair to say that participatory methods have not been applied to anywhere near their full potential in energy whole-systems modelling. However, the benefits highlighted in research from the socio-economic systems and environmental domains, as well as the few examples presented in energy, show the potential for supporting decision-making at different scales. Future work in this area is warranted and we will be exploring the direction that this should take in a stakeholder workshop.

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Table 1 — Summary of participatory modelling methods

PM methods	Short description	Originator	Key literature	Application	Notes
Group model building	Development of causal loop diagrams and systems dynamic models	Netherlands and later Decision techtronics Group	(Vennix, 1999, Vennix et al., 1997)	Business and natural resource management *(See section 3.1 for energy example)*	Most extensive PM method used – but particular to systems dynamics modelling (and therefore the limitations of that method)
Mediated modelling	Similar to GMB, involving SD but applied to environmental applications	Mediated Modelling Partners	(Van den Belt, 2004)	Environmental	
Companion modelling	Stakeholder process involving agent-based models and role-playing games	CIRAD (France)	(Barreteau et al., 2003, Étienne, 2013)	Virtually all companion modelling has been undertaken in relation to environmental and agricultural domains (Moss, 2008) *(See section 3.2 for energy example)*	
Participatory simulation	Use of online simulation models	Systems dynamics group at MIT		Varied	May not be participatory if settings and rules of the game/model cannot be modified
Shared vision planning (related to scenario visioning)	Mostly applied use of Excel and SD models, also numerical modelling	US Army Corps of Engineers		Applied e.g. resource management conflict resolution *(See section 3.3 for energy example)*	Hardly any peer-reviewed papers, though scenario visioning is more common in academic work