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Participatory Modeling Updates Expectations for Individuals and Groups, Catalyzing Behavior Change and Collective Action in Water-Energy-Food Nexus Governance

C. Kimmich[1], L. Gallagher[2], B. Kopainsky[3], M. Dubois[4], C. Sovann[5], C. Buth[6], and C. Bréthaut[2]

[1]Faculty of Social StudiesDepartment of Environmental Studies, Masaryk University, Brno, Czechia, [2]Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland, [3]System Dynamics Group, Department of Geography, University of Bergen, Bergen, Norway, [4]WorldFish Myanmar – Fish CGIAR Research Program, [5]Department of Environmental Science, Royal University of Phnom Penh, Phnom Penh, Cambodia, [6]Mekong Flooded Forest Landscape Team, World Wide Fund for Nature, Kratie Province, Cambodia

Key Points:
- Participatory modeling could be fundamental to understanding complex social-ecological systems with high uncertainty and conflicting interests
- Engagement in participatory modeling can change expectations and thereby increase individual and collective agency in facing sustainability challenges
- Our method provides a framework to evaluate and compare participatory modeling approaches for their behavior change potential

Supporting Information:
- Supporting Information S1
- Data Set S1

Correspondence to:
L. Gallagher,
louise.gallagher@unige.ch

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Author Contributions:
Conceptualization: C. Kimmich, L. Gallagher, B. Kopainsky, M. Dubois, C. Bréthaut
Data curation: C. Kimmich, B. Kopainsky, M. Dubois, C. Sovann
Formal analysis: C. Kimmich, L. Gallagher
Funding acquisition: L. Gallagher, C. Bréthaut
Investigation: B. Kopainsky, M. Dubois, C. Sovann, C. Buth
(continued)

Abstract Participatory modeling is a potentially high-impact approach for catalyzing fundamental sustainability transformations. We test if participation in a group system dynamics modeling exercise increases participants' agency through a novel method to evaluate potential behavioral change using expectation measures. A water-energy-food nexus—a functionally interdependent but underconceptualized system with low consensus and high scientific uncertainty—was mapped, and its evolution simulated by 46 participants in three interventions in a region undergoing hydropower infrastructure development in Northeastern Cambodia. Participants' system-related expectations were measured before and after the interventions. Our results suggest that participants became significantly more optimistic about their individual agency to increase agricultural and fishing income and, interestingly, less likely to participate in local government development planning procedures. Findings also reveal how some uncertainties for multiple variables were reduced within and across the groups. Such converging expectations suggest that participatory modeling could contribute to making collective solutions and institutionalized agreements more likely. This research contributes to innovation in sustainability because it unpacks some underlying mechanics of how participatory processes can lead to new adaptive capacities, shared perspectives, and collective actions.

Plain Language Summary Our research contributes to understanding actionable knowledge for sustainability using a before-after intervention with fishing and farming community representatives in a situation of conflicting water, energy, food, and livelihoods priorities in rural Cambodia. We explain why reducing uncertainty and building consensus on action through participatory research could potentially catalyze new behavior that promotes sustainability and test how this happens in our intervention. The result is a new and much needed evaluation framework and method for behavioral change outcomes in sustainability interventions.

1. Introduction

Sustainability transformations necessarily happen under huge uncertainty about future pathways and actions to take (Abson et al., 2017). Empowerment is a critical component of adaptive capacity, agency, and behavior change needed to navigate such uncertainty. Collaborating with stakeholders in research across and beyond disciplines (Pahl-Wostl et al., 2013; Pohl et al., 2010) produces new knowledge that can address some uncertainties (Addor et al., 2015; Yung et al., 2019) and empower communities and individuals to develop new pathways (Gerritsen et al., 2013; Miller & Wyborn, 2018). Progress has been made on better understanding knowledge coproduction (Dubois et al., 2016) and its outcomes (DeLorme et al., 2016; Miller & Wyborn, 2018). However, we know much less about specific mechanisms that may induce participants in these processes to change behavior (Carr et al., 2012; Smajgl & Ward, 2015) and why this new behavior might catalyze sustainability outcomes.

Methodology: C. Kimmich, L. Gallagher, B. Kopainsky, M. Dubois, C. Sovann, C. Bréthaut
Project administration: L. Gallagher, C. Bréthaut
Resources: L. Gallagher, M. Dubois, C. Buth
Supervision: L. Gallagher, B. Kopainsky, M. Dubois, C. Sovann, C. Bréthaut
Validation: C. Kimmich, L. Gallagher, B. Kopainsky, M. Dubois, C. Buth
Visualization: C. Kimmich, B. Kopainsky
Writing - original draft: C. Kimmich, L. Gallagher
Writing – review & editing: C. Kimmich, L. Gallagher, B. Kopainsky, M. Dubois, C. Sovann, C. Buth, C. Bréthaut

Though participatory research is framed differently across sustainability domains, two core assumptions seem to dominate. First, that knowledge produced through participatory processes is more likely to identify transformational leverage points (Star & Griesemer, 1989) and feasible responses for tackling complex sustainability challenges because the knowledge is coproduced from multiple perspectives (Cash et al., 2003). Second, such participatory research can directly and indirectly influence behavior change required for realizing sustainability pathways (Gerritsen et al., 2013). However, epistemological, ontological, and methodological issues for integrating knowledge and engaging with values, power, and politics remain so significant (Jordan et al., 2018; Miller & Wyborn, 2018; Wesselink et al., 2013) that such assumptions need to be constructively challenged if we are to innovate a scalable, deliberate, and thoughtful practice for participatory research in sustainability.

Participatory modeling is suited to address less structured problems where consensus is low, uncertainty is high, and collaboration, co-decision, and joint action are needed (Basco-Carrera et al., 2017; Hurlbert & Gupta, 2015). Compliance-based thinking dominates in rationalizing uses of participatory modeling (Basco-Carrera et al., 2017), suggesting the primary reason for stakeholder participation in model building is to increase acceptability, ownership, and legitimacy of modeling results. In sustainability science, participatory modeling is celebrated for social learning about systems and root causes of problems, providing multiple perspectives in decision support for policy design, increasing adaptive capacity, and enabling coordinated action (Hedelin et al., 2017; Voinov et al., 2016). Participation in model development has received far less attention as a field of practice and research, compared to focus groups, citizen panels, or participatory rural appraisals, however (Scott et al., 2016b). We argue this overlooks the potential contribution to behavior change of the process of participatory modeling itself.

Participatory modeling has been called a cultural process (Crane, 2010) that can reveal key uncertainties in play and resolve some of these through facilitating information sharing, group problem and action analysis, deliberation, and negotiation (Rouwette et al., 2011; Rouwette & Vennix, 2006). Comparative analyses of participatory modeling techniques attest to effects on social capital (Davies et al., 2015) and on participant mental models and attitudes (Scott et al., 2016b), which are theorized as key determinants of behavior (Denzau & North, 1994; Rodrik, 2014). However, there have been no explorations of their impact on participants' expectations even though expectation changes are strong predictors of behavior change (Delavande et al., 2011b; Jensen, 2010; Kimmich & Fischbacher, 2016; McKenzie et al., 2013) and are likely influenced by changes in both individual and shared mental models (Glynn et al., 2017). Expectations have been shown to predict behavior in a number of different areas and field settings, including expected income and education (Manski, 2004), income and migration (McKenzie et al., 2013), coffee prices and labor allocation (Hill, 2010), wood prices and industrial organization (Kimmich & Fischbacher, 2016), or monsoon onset and planting decisions (Giné et al., 2009). See Delavande et al. (2011b) for a review.

This research contributes to understanding the actionable dimension of "actionable knowledge" production by testing behavioral change efficacy in participatory systems modeling using a before-after intervention design in field conditions. We tested behavior change in a participatory systems thinking and modeling procedure called causal loop diagram (CLD) mapping and simulation (Kopainsky et al., 2017) conducted with fishing and farming community stakeholders in Kratie Province, the site of burgeoning water-energy-food (WEF) nexus tensions in Northeastern Cambodia in the Mekong River Basin. Theoretically, we provide explanations for the mechanisms of behavioral change resulting from systems thinking- and modeling-based interventions. Empirically, our field results show support for a recent proposition in the behavioral literature that intervening to change expectations can drive changes in behavior. Methodologically, we contribute a novel and needed evaluation framework for behavioral outcome evaluation in sustainability interventions. Practically, we derive lessons for participatory sustainability research and practice. These four contributions have implications for design and evaluation of programs, projects, networks, and partnerships in sustainability.

2. Materials and Methods

2.1. Hypotheses

We define efficacy of participatory system modeling interventions as actual and prospective behavioral change that was intended and induced by the intervention. This includes all types of individual behaviors, either at the household and farm scale, or as part of organizations.

We formulate two hypotheses to evaluate whether these processes are likely to elicit new behavioral change in participants. We hypothesize that participant expectations concerning (1) the likelihood of certain future events and (2) their own individual agency to respond to these events will change because of the intervention. We assume that optimism or pessimism regarding future outcomes will be affected by these expectations and, in turn, influence future choices in behavior. This activation hypothesis relates to the theory on self-efficacy in bringing about specific expected outcomes (Gittelsohn et al., 2012) and empowerment outcomes from participatory modeling (Basco-Carrera et al., 2017). Self-efficacy is a key component of empowerment (Diener & Biswas-Diener, 2005). The hypothesis suggests that participants become more optimistic about their individual opportunities under their control, rather than external outcomes that they cannot influence.

We also postulate that participatory modeling reduces uncertainty and enables convergence in expectations across members of the group. Shared expectations are an important prerequisite for collective action (Runge, 1986) and therefore fundamental to institutional innovation and making choices about shared resources. Once participants converge on the likelihood of an event or outcome, support for an institutional solution becomes common knowledge, which facilitates collective choice. We assume that joint exploration of system properties in a participatory modeling protocol leads to shared mental models (Scott et al., 2016b) and hypothesize that convergence dominates divergence in expectations-forming across participants. We focus on uncertainty at the group level rather than changes in individuals' uncertainty, which would require expectation elicitation of multiple intervals, exceeding survey time constraints when multiple expectation variables are measured.

2.2. Case Selection: Why Focus on Participatory Processes in WEF Nexus Governance?

We chose to test our hypotheses in the nexus context using participatory CLD mapping and simulation. Three reasons led us to choose this method and context:

First, with increasing pressures on natural resources, and externalities and trade-offs between sectors becoming more visible (Al-Saidi & Elagib, 2017), the WEF nexus has emerged as an important phenomenon and theme in sustainability (Gallagher et al., 2016; Liu et al., 2018). While a vast number of WEF nexus frameworks have emerged within less than a decade, agreement on key ingredients of this socioecological system has not been achieved (Albrecht et al., 2018; Allan et al., 2015; Allouche et al., 2015; Villamayor-Tomas et al., 2015). In this respect, low consensus on methods (Kaddoura & El Khatib, 2017), conflicting interests (Fox & Sneddon, 2019; Lebel & Lebel, 2018), and scientific uncertainty make the WEF nexus a paradigmatic case for sustainability science (Boyd et al., 2015; Cash et al., 2003; Hurlbert & Gupta, 2015).

Second, model-based decision support is an area ripe for innovation in sustainability research (Basco-Carrera et al., 2017; Gerritsen et al., 2013; van Voorn et al., 2016). New insights on how this form of knowledge production and use could translate to behavior change have potential to scale given its common usage. The WEF nexus makes a good case precisely because its computational modeling frameworks and methodologies (Albrecht et al., 2018) are currently debated (Kaddoura & El Khatib, 2017) and evolving to operationalize the WEF nexus usefully in governance and decision making (Shannak et al., 2018; Weitz et al., 2017).

Finally, WEF nexus governance research is increasingly concerned with questions of participation. WEF nexus governance requires complex adaptation among a large set of stakeholders with all the attendant uncertainties, politics, and power dynamics (Allouche et al., 2015; Foran, 2015; Gallagher et al., 2019). We now understand that tracing causes of problems and potential responses in WEF nexus governance requires transdisciplinary systems thinking (Hagemann & Kirschke, 2017; Howarth & Monasterolo, 2017). Public participation has been extensively addressed by research on challenges of inclusion of different stakeholder groups in decision making and the varying degrees of legitimacy and success implied by such processes (see, among others, Fung, 2006; Irvin & Stansbury, 2004; Reed, 2008; Heijden & Heuvelhof, 2012). A particular subset of WEF nexus governance literature has shown that participatory modeling holds some potential for anticipatory governance (Boyd et al., 2015; Guston, 2014) in river basin WEF nexus situations (Sendzimir et al., 2007; Smajgl et al., 2015; Smajgl & Ward, 2013). It can be useful to address the complexity of stakes in WEF nexus governance (Halbe et al., 2015; Howarth & Monasterolo, 2017; Smajgl & Ward, 2013). It has been shown to increase understanding of empirical reality and intricacy by integrating different perspectives and narratives related to WEF nexus intersectoral challenges (Gallagher et al., 2019). It facilitates knowledge sharing and integration (Hagemann & Kirschke, 2017) and has been used to open new formal or informal deliberations between WEF nexus actors, as well as reinforcing existing science-policy interfaces (Smajgl et al., 2015). Yet the link between participation and anticipatory governance outcomes is underdeveloped (Smajgl & Ward, 2015). Exploring the effect of participatory modeling may have on actor behavior in WEF nexus governance systems is a critical next step in this strand of research.

2.3. Place-Based Case Selection, Sampling Procedure, and Participant Identification

The Mekong River Basin is the site of large-scale and largely uncoordinated hydropower development in a situation of rapid climate and socioeconomic changes, where the Mekong River Commission is the primary intergovernmental body for cooperation between the lower basin riparian countries (Viet Nam, Thailand, Lao PDR, and Cambodia) and upstream partners (China and Myanmar). Hydropower is viewed as a poverty reduction measure in this region, and yet these infrastructures are also expected to impact significantly on ecosystem integrity, fisheries and agricultural systems, and, subsequently, nature-based livelihoods and food production (Mekong River Commission, 2017; Molle et al., 2012).

Mekong fishers and farmers are and will continue to operate in a complex situation, making decisions under a large degree of future uncertainty. Navigating this WEF nexus has been an ongoing challenge for the transboundary governance of this globally significant river basin. The CGIAR WLE (CGIAR's Research Program on Water, Land and Ecosystems) Challenge program on water and food (2002–2013) and subsequent research investments on various dimensions of the Mekong WEF nexus (Gallagher et al., 2019; Foran, 2015; Grafton et al., 2016; Lebel & Lebel, 2018; Molle, 2009; Middleton et al., 2015; Orr et al., 2012; Pittock et al., 2016; Smajgl & Ward, 2013; Smajgl et al., 2015; Villamayor-Tomas et al., 2016) mean this is one of the best researched WEF nexus cases globally. Our Mekong WEF nexus case study is a WEF situation in Kratie Province, Cambodia (Liu et al., 2018). Local communities in this region will be impacted by two major hydropower projects in Cambodia: Stung Treng dam in Stung Treng Province, a proposed mainstem (central river channel) gravity dam being built for energy export to Thailand; and Sambor dam in Kratie Province, the largest proposed dam in the entire river basin (Wild et al., 2019; Wu et al., 2010). Kratie and Stung Treng Provinces are also experiencing other forms of development that impact the agricultural and fishing activities that currently support local populations' subsistence and livelihoods in different ways. Rubber plantation expansion, river bed sand mining, and road network infrastructure are all in progress, alongside a burgeoning ecosystem-based tourism sector driven by the presence of rare and endangered Irrawaddy freshwater dolphins (Kratie Provincial Department of Planning, 2014).

With natural resource exploitation closely linked to fraught domestic politics (Milne & Mahanty, 2015; Un & Sokbunthoeun, 2009) and poor local participation in large dam planning (Siciliano et al., 2015; Sithirith, 2016), local government development planning processes are the major formal planning mechanisms open to people in places like Kratie Province. Local-level priority and concerns are identified at commune level (the third level of local government administration in Cambodia, below district and provincial administrations) by Commune Councils in a 3-year rolling Commune Development Plan (CDP), which is then reviewed annually to produce a Commune Investment Plan (CIP) for the year. The CDP/CIP dominates local formal development planning (Plummer & Tritt, 2012) as an institution dating back to French colonial times and the first level of government administration to be reestablished following the civil war (Öjendal & Lilja, 2009). In principle, it is a good process that relies on and encourages citizen participation to build legitimacy. There are many concerns about how it works in practice, however (Milne & Mahanty, 2015; Plummer & Tritt, 2012; Vuković & Babović, 2018).

Underfunded, and conducted in the context of specific cultural and sociopolitical dynamics of Cambodia's rural areas, the annual CIP rarely challenges the CDP or other plans generated higher up in the political hierarchy (Öjendal & Sedara, 2006; Sedara, 2012), and infrastructure (often roads and local irrigation projects) is identified repeatedly as the main priority without any evidence as to its effectiveness in poverty reduction. A process of decentralization and deconcentration of government functions (hereafter "D&D reforms") is shifting government toward more transversal service delivery goals with new local planning procedures to encompass district and commune plans (Sedara, 2012; Royal Decree No. NS/RKM/1208/1429 2008; Royal Decree no. NS/RKM/1014/1174 2014). However, the D&D reforms face their own implementation challenges (Cambodia Development Resource Institute, 2004; National Committee for Sub-National Democratic Development, 2010, 2017), and with no current alternatives, local people engage in CIP meetings.

10.1029/2019EF001311

We chose to select participants from villages in communes within Kratie Province that are in proximate distance to the Mekong River channel to assure that a majority of our participants were involved in the local manifestation of complex intersectoral issues and involved at the scale of which response planning will likely take place. Drawing on the Cambodian Commune Council Database (National Committee for Sub-National Democratic Development, 2015), we instrumentally selected (Gerring, 2007) two villages along the Mekong in Cambodia where some of the WEF nexus dynamics are paramount (Allouche et al., 2015; Lebel & Lebel, 2018; Pittock et al., 2016) based on criteria that made it more likely we would capture WEF nexus dimensions in the models. Dependence on natural resources and proximity to water bodies had to be high. We wanted some recent technology adoption to be present, to capture potential emerging adaptive dynamics as a region that has had limited electricity connections but seeks to increase energy access. Furthermore, alternative livelihoods, including resource-dependent and resource-independent incomes, had to be present. Therefore, we chose one village with solar photovoltaic system (PV) use (Damrae, G1), while the other has ecotourism (Koh Phdao, G2).

Representative sampling within each community is hard to achieve. Although community-level data are available to identify numbers of people of age cohorts, employment, and so on, there is no name list that could be used for randomized sampling. In addition, we needed a subsample of farmers and fishers. Given that real-world group sampling procedures are frequently nonrandom by design and can yield valid inferences if carefully analyzed (Harrison & List, 2004; Smith, 1983), we decided to target heterogeneity on the basis of age, gender, and education, including village chiefs' subjective judgments about participants' knowledge about farm and fisher livelihoods. Among the villagers, we selected participants from the fishing and farming communities, with some of them officially employed and involved in political processes at the commune level. We aimed to sample a maximum heterogeneity along the dimensions of gender, age, education, and wealth. The objective was to integrate a variety of perspectives into the procedure with the underlying assumption being that demographic heterogeneity is related to variation in expectations and therefore strengthens the hypothesized effects of the intervention. We did not test for the effects of diversity but rather controlled for some of the potential effects of demographics through related survey items (see the supporting information section S3 for an analysis of group and gender effects).

A purposefully heterogeneous composition was achieved by stratified sampling to guide selection to include members of farming and fishing households of both genders and different ages. The village chief's local knowledge, together with local field expert interviews, and review of demographic information and existing infrastructure in the Cambodia Commune Database (National Committee for Sub-National Democratic Development, 2015) and Commune Investment Plan 2014 (Kratie Provincial Department of Planning, 2014) supported the selection. The data sources are formal government data and are not always freely available or up to date. We accessed them through personal contacts in the Ministry of Interior and the Provincial Administration in Kratie.

2.4. The Participatory Modeling Intervention

Our intervention protocol describes and simulates the current livelihood and environmental condition situation in the region through explicit scenario modeling, using participants' knowledge and facilitating dialogue about future risks and potential actions to mitigate or adapt to these.

The type of participatory modeling matters (Davies et al., 2015). We employed a CLD procedure that involves stakeholders selecting essential variables, developing causal effects between them, and then simulating development of these relationships into the future through scenario analysis (Kopainsky et al., 2017). Though simulation is rarer, CLD mapping has been applied in many cases (Hovmand et al., 2012). A combination of socio-ecological system indicator selection and participatory simulation has been recently applied to coastal management in the Dutch Wadden Sea (Vugteveen et al., 2015). A matrix approach to facilitating causal link development has been applied to coastal management in Egypt (Sanò et al., 2014), and individual model aggregation has been addressed in a participatory CLD mapping and simulation process on the Volta River Basin (Kotir et al., 2017).

The optimal group size has been reported at around 15 participants in the literature (Phillips & Phillips, 1993). Accordingly, two CLD mapping and simulation exercises were conducted with two groups of 15 participants from the two different villages sampled for the intervention. The third intervention was a mixed group of 16 participants consisting of inhabitants from both villages, without including any participant from the other two groups. With this mixed group, we tested for the effects of integration between the two village perspectives (PV use and ecotourism) on the CLD intervention (see supporting information for details of group comparison).

The CLD intervention design was grounded in the participatory system dynamics literature but further adapted to groups at the community level with low formal educational background (Kopainsky et al., 2017). We avoided computer simulation and mapped with physical materials (Hovmand et al., 2012) that included a hands-on simulation exercise (Kopainsky et al., 2017). Participants engaged in identifying key variables, mapping relationships between them. The current situation and related problems were then simulated using glasses of water to depict stocks and flows to represent time-dependent change in stock levels to develop and explore future scenarios collectively. Afterward, solutions were identified and grouped according to actions by individual and commune-level actors and then simulated for future outcomes.

Using scripts that serve as replicable protocols (Hovmand et al., 2012), the intervention was led by one group facilitator and one modeler/technical advisor and guided by several research assistants acting as process coaches (Hovmand, 2014). The CLD procedure lasted between 3 and 4 hr. Figure 1 provides an example of a CLD produced by Group 3 (G3). The protocol, the underlying scripts, and the Group 1 (G1) and Group 2 (G2) outcomes are included in the supporting information.

3. Data

3.1. Intervention Design for Hypothesis Testing and Data Collection

We developed a novel evaluation procedure based on an empirically supported assumption that peoples' expectations about the future drive their behavior (Delavande et al., 2011b; Jensen, 2010; Kimmich & Fischbacher, 2016; McKenzie et al., 2013), hypothesizing that the learning enabled by participatory modeling (Hedelin et al., 2017) reduces uncertainty by updating participant expectations and increasing their agency to respond to future change. Our design involves a within-subjects treatment with before and after surveys. We measured expectations before and after the intervention, building on behavioral economic theory (Manski, 2004) and recent empirical evidence (Delavande et al., 2011b; Jensen, 2010; Kimmich & Fischbacher, 2016; McKenzie et al., 2013). The intervention design and survey were pretested in February and conducted in March 2018. All participants received the same treatment, which took approximately 6 hr in total.

We tested general treatment efficacy with the difference between a pretreatment and posttreatment measurement of expectations as behavioral proxies, provided by the surveys. Differential efficacy was measured as relative efficacy between the three groups, comparing the two villages and the mixed group. Note that we did not measure differential efficacy between the CLD intervention and any other form of intervention, which would require respective control groups.

We elicited subjective expectations to measure prospective behavioral change. The method of eliciting expectations with subjective probabilities is preferable over Likert scales or other elicitation methods (Manski, 2004). In the developing economy context, even with illiterate subjects, subjective probability measures have been shown to be understood, internally consistent, and frequently highly accurate when compared to actual realizations and past experiences (Delavande et al., 2011a).

Visual aids help improve accuracy of returns, especially in mixed cultural and linguistic contexts (Delavande et al., 2011b). We used predefined binary classes and used coffee beans as a measure to support elicitation. An elicitation pretest suggested that the tactile dimension of using coffee beans leads to a more reflected weighing than percentage number elicitations. A test for potential biases is still missing, however. We did not incentivize questions with payments to expectations answers, which is in line with common practice and supported by empirical findings (Delavande et al., 2011b).

We tested whether participants understood the concept. The first three questions and related expectations items tested the two extremes and equal probabilities. Table 2 provides descriptive statistics for the expectations items. Figures 1 and 2 provide box plots of the distributions before and after the treatment and the changes, respectively. The results were supportive. The median corresponded to the expected value in all three questions (see Table 2). The mean indicates that there was nevertheless a share of farmers who did

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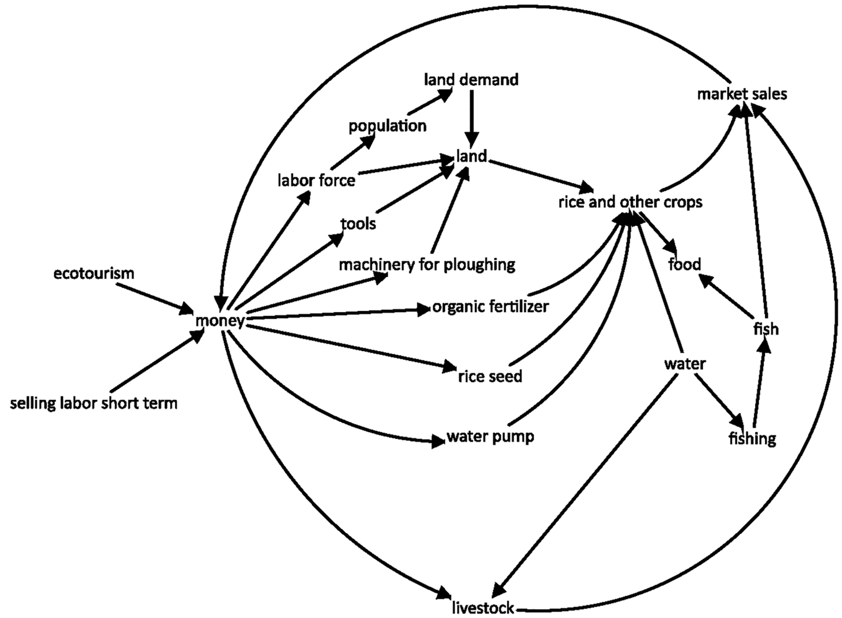

Figure 1. A causal loop diagram produced by Group 3 in our intervention in approximately 45 min of discussion and deliberation (see Script S4 in the supporting information). It depicts key variables and the cause-and-effect relationships linking them, as identified by the group participants with the support of facilitators.

not expect the sun to rise with certainty and did expect the river to run dry. There was also a considerable share of participants (42.86%) who expected the next child in their household to be a boy more or less likely than did 50%. Overall, however, there has been a learning effect, as the mean moved toward the median and the standard deviation (SD) decreased for each of the three questions.

We also tested whether participants understood nested probabilities using an adapted set of questions concerning the occurrence of a drought in Cambodia (like the one in 2015/2016) within 5 and 10 years, respectively. Two farmers had inconsistent expectations, stating that a drought within 5 years was more likely than was a drought within 10 years. This deviation of 4.35% is slightly higher than what has been found in another consistency test (Delavande et al., 2011b).

We elicited the following variables to control for demographic and household characteristics: A set of questions concerning gender, age, and education controls for basic demographics. We also included a set of questions concerning household size and position of the surveyed person in the household. Sources of household income were differentiated to capture income from farming, fishing, tourism, and public and private employment. We also include items on food self-provision and expenditure for food to account for households' semi-subsistence. Households' vulnerability to food insecurity and food quality was covered to control for potential effects on expectation measures. For example, Indian farmers' monsoon predictions have been shown to be influenced by their dependence on rain-fed irrigation (Giné et al., 2009).

Finally, we also tested whether the CLD intervention could influence more qualitative expectations dimensions unlikely to appear in the model. This allowed us to separate the effects of the CLD intervention from communication effects or information sharing that happens naturally while building the CLD.

3.2. Data Analysis Strategy

Employing nonparametric tests instead of *t* tests is recommended with small samples and when *t*-test distributional assumptions are likely to be violated. A Shapiro-Wilk test for normality (see Table S2 in the supporting material) showed that there is a statistically significant deviation from normality for the tests not only for extremes (sunrise and river) but also for expectations related to fish income, organic fertilizer effects on income and food quality, others' and own decision to invest into a pump, and participation in the annual CIP. We therefore chose nonparametric tests, using the Wilcoxon signed-rank test for paired samples, which tests for a zero difference of the median before and after the treatment. We compare the results with the exact

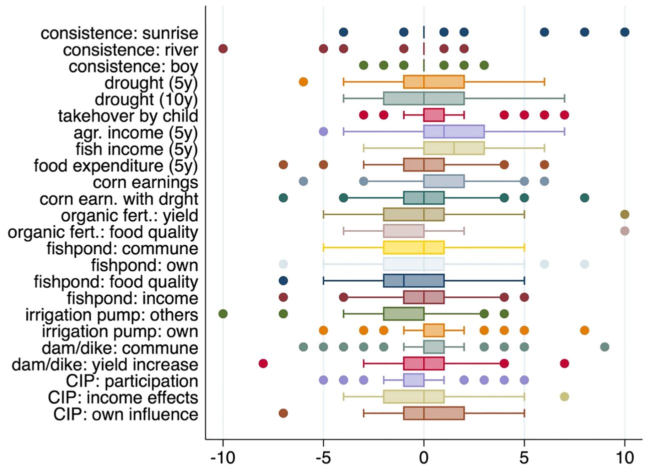

Figure 2. Box plots of the changes in expectations for our key variables. "Drought": likelihood of a drought like in 2015/2016 reoccurring; "Take over by child": likelihood that the family farm or fishing activity will be taken over by someone from the family; "Agr. Income": likelihood that household income earned through agricultural activities will increase; "Fish income": likelihood that household income earned through fishing activities will increase; "Food expenditure": likelihood that the share of food bought rather than produced by the household will increase in the next 5 years; "Corn": likelihood the household would earn more from planting corn than from rice in the next season, and then under drought conditions; "Organic fert.": likelihood that yields would be higher with organic fertilizers than with conventional (chemical) fertilizers, and expected effects on food quality; "Fishpond": likelihood that a new fishpond will be constructed in the commune within the next 5 years, by the respondent or someone else, and the anticipated implications for food quality and household income; "Irrigation pump": likelihood that someone else or the respondent would purchase a water pump in the next 5 years; "Dam/dike": small dikes or dams will be constructed by respondent's commune within the next 5 years and anticipated implications for agricultural production; "CIP": likelihood that the respondent will participate in the CIP process within the next 5 years, that CIP decisions will have a positive effect on household income of the respondent, and that the respondent could influence a CIP decision.

Wilcoxon signed-rank test (Harris & Hardin, 2013), which supported previous findings. Note that due to the small sample size, the power of the tests is relatively low. The statistical test results provide only preliminary support for the hypotheses.

One assumption of the Wilcoxon test is independent sampling within and between groups. This assumption is violated with clustered data of the type we produced in our three intervention groups. Newson's method to calculate confidence intervals and Somers' *D* can account for clustered data, however (Newson, 2002). We therefore compared our results with the results from Newson's method, comparing them with both clustered and nonclustered results. Table S3 in the supporting information reports Somers' *D* without clustering, which can be compared with the Wilcoxon signed-rank test results in the main text.

4. Results and Discussion

Instrumental sample selection provided an equal distribution along gender and heads of households and a large variation in terms of age and education (Table S1). Standard consistence tests used in expectation elicitation procedures, testing extremes, equal, and nested probabilities assured that participants understood the concept (see consistence items in Table 1 and section 2).

4.1. Individual Empowerment Results

Recalling that our activation hypothesis proposes that affecting self-efficacy in participatory modeling brings about specific empowerment outcomes (Basco-Carrera et al., 2017; Diener & Biswas-Diener, 2005; Gittelsohn et al., 2012), we test if participants become more optimistic about the opportunities directly under their control.

We asked the participants: "How likely do you think it will be that your income from agricultural production (and fishing, respectively) within the next five years will increase?" Using the nonparametric Wilcoxon signed-rank test, we found statistical support for the general income expectation variables over which participants have control. Participants were significantly more optimistic concerning their farm- and fishing-related incomes after the intervention; that is, we can reject the null hypothesis for agricultural income ($P > 0.008$) as well as income from fishing ($P > 0.002$).

We also tested whether such increased optimism could derive from specific agricultural techniques, rather than from a more general empowerment effect. Neither fishpond income ($P > 0.92$) nor effects of the CIP on income ($P > 0.75$) contributed to this optimism. With the help of Somers' *D*, we can also interpret the effect size. Concerning agricultural income, for example, participants are between 11% and 42% more likely to expect their income from agriculture to increase than to decrease after the CLD intervention (see Table 2).

The Wilcoxon signed-rank test findings are supported by Newson's method (see section 2), accounting for clustered data across the three intervention groups (see Table 2). While agricultural and income expectations changed significantly, the source of this optimism is neither directly related to fishpond nor related to CIP income expectations, where no significant changes could be observed. Increasing optimism about children taking over farming or fishing activities is in line with more optimistic income expectations.

We also found statistically significant changes in other expectation variables modeled by the participants. We found a decrease in expected likelihood that somebody in the community will invest in a pump and that the commune will invest in a fishpond. The findings concerning raised expectations for earnings from corn planting during droughts are not robust when compared with other model specifications (see nonclustered results in Table S3).

Table 1
Summary Statistics of the Expectation Variables Before and After the Intervention for Three Consistence Tests and 21 Key Variables

		Before					After				
Variable	*N*	Mean	SD	Med	Min	Max	Mean	SD	Med	Min	Max
consistence: sunrise	42	7.17	4.15	10	0	10	8.19	3.12	10	0	10
consistence: river	42	2.10	3.47	0	0	10	0.98	2.40	0	0	10
consistence: boy	42	4.45	1.98	5	0	10	4.48	1.71	5	0	9
drought (5y)	46	4.98	2.13	5	0	10	5.20	1.68	5	1	10
drought (10y)	46	6.02	2.71	6	0	10	6.24	1.99	6	3	10
takeover by child	46	5.09	2.78	5	0	10	5.76	2.46	5	1	10
agr. income (5y)	46	5.15	2.25	5	0	10	6.13	1.68	6	3	10
fish income (5y)	46	2.70	2.18	3	0	8	4.02	2.15	4	0	8
food expenditure (5y)	46	5.04	2.39	5	0	10	4.91	1.56	5	1	7
corn: earnings	46	3.70	2.23	4	0	8	4.33	2.12	4	0	9
corn: earn. with drought	46	3.80	2.62	3.5	0	10	3.89	2.49	4	0	8
organic fert.: yield	46	7.35	2.51	8	0	10	7.00	2.42	8	0	10
organic fert.: food quality	46	8.76	1.90	10	0	10	8.30	1.58	8	4	10
fishpond: commune	46	5.50	2.18	5	0	10	5.02	2.18	5	0	10
fishpond: own	46	5.17	3.10	5	0	10	5.17	2.60	5	0	10
fishpond: food quality	46	6.98	1.89	7	2	10	6.57	1.60	7	2	9
fishpond: income	46	6.61	1.89	7	2	10	6.57	2.12	7	1	10
irrigation pump: others	46	6.78	2.70	7	0	10	6.15	2.61	7	0	10
irrigation pump: own	46	6.74	3.30	7	0	10	7.17	2.96	8	0	10
dam/dike commune	46	3.96	2.81	5	0	10	4.24	2.58	5	0	10
dam/dike yield increase	46	6.30	2.05	7	1	10	6.43	2.21	7	0	10
CIP: participation	46	7.46	2.33	8	0	10	7.13	2.17	7.5	2	10
CIP: income effects	46	6.20	2.48	6.5	1	10	6.30	2.00	7	2	10
CIP: own influence	46	5.33	2.39	5	0	10	5.48	2.27	5	1	10

We also tested for variables that were unlikely to be modeled explicitly in a CLD framework to identify the potential effects of communication during the modeling process. We found a significant decrease in expected food quality from the application of organic fertilizers and suppressed expectations about food quality from fishpond investments (although less statistically robust, see Table S3). Given that food quality was not modeled by any of the groups (see section 2), this result shows that the CLD mapping and simulation was not the only instrument shaping expectations during the intervention. Participants went beyond the boundary object of the CLD intervention to form new expectations independently for variables not discussed by the group.

In brief, we found support for the activation hypothesis. The optimism concerning agricultural and fishing income seems to be general and cannot be traced to any specific agricultural method, such as pump or fishpond investments, or earnings from corn. Therefore, we cannot trace this optimism to any specific production. Importantly, this increase in optimism is not in line with other findings on agricultural income expectations in Cambodia (Grafton et al., 2016; Scheidel et al., 2014). Rather, this optimism appears to be a more general phenomenon resulting from having participated in the CLD procedure.

4.2. Shared Expectations and Collective Action Results

Shared expectations are an important prerequisite for collective action (Runge, 1986) and therefore fundamental for institutional innovation. Once participants converge on the likelihood of an event or outcome, support for an institutional solution becomes common knowledge that facilitates collective choice. We assume that joint exploration of system properties in a participatory modeling protocol leads to shared mental models (Scott et al., 2016a) and hypothesize that convergence dominates divergence in expectations-forming across participants. We focus on uncertainty at the group level rather than changes in individuals' uncertainty, which would require expectation elicitation of multiple intervals, exceeding survey time constraints when multiple expectation variables are measured.

The results show that the CLD intervention has contributed to some convergence in expectations and a related reduction in uncertainty in our groups. We compared the SD of each variable before and after the

Table 2
Within-Cluster Somers' D With Standard Errors Adjusted for the Three Groups

CLD_treatment	Coefficient	Jknife SEs	z	P > z	95% confidence interval	
drought (5y)	0.0623229	0.0935694	0.67	0.505	−0.1210698	0.2457156
drought (10y)	−0.0028329	0.0790037	−0.04	0.971	−0.1576772	0.1520115
takeover by child	0.1331445	0.0738423	1.80	0.071	−0.0115837	0.2778727
agr. income (5y)	0.2677054	0.0790918	3.38	0.001	0.1126882	0.4227225
fish income (5y)	0.3541076	0.1022549	3.46	0.001	0.1536918	0.5545235
food expenditure (5y)	−0.0524079	0.1248944	−0.42	0.675	−0.2971965	0.1923806
corn: earnings	0.1657224	0.1362876	1.22	0.224	−0.1013964	0.4328411
corn: earn. with drought	0.0410765	0.0233324	1.76	0.078	−0.0046541	0.0868071
organic fert.: yield	−0.0963173	0.1450005	−0.66	0.507	−0.3805131	0.1878785
organic fert.: food quality	−0.2294618	0.0467748	−4.91	0.000	−0.3211387	−0.1377848
fishpond: commune	−0.0991501	0.0470523	−2.11	0.035	−0.191371	−0.0069293
fishpond: own	−0.0212465	0.0159911	−1.33	0.184	−0.0525885	0.0100955
fishpond: food quality	−0.1458924	0.0834862	−1.75	0.081	−0.3095223	0.0177376
fishpond: income	0.0254958	0.0967985	0.26	0.792	−0.1642259	0.2152174
irrigation pump: others	−0.1203966	0.0479123	−2.51	0.012	−0.2143031	−0.0264901
irrigation pump: own	0.0538244	0.0553522	0.97	0.331	−0.0546641	0.1623128
dam/dike: commune	0.0694051	0.0799335	0.87	0.385	−0.0872616	0.2260718
dam/dike: yield increase	0.0609065	0.0625659	0.97	0.330	−0.0617204	0.1835335
CIP: participation	−0.1033994	0.0360144	−2.87	0.004	−0.1739864	−0.0328125
CIP: income effects	0.0354108	0.0355212	1.00	0.319	−0.0342095	0.1050311
CIP: own influence	−0.0042493	0.0297723	−0.14	0.887	−0.0626019	0.0541033

Note. The table shows the results of testing the hypothesis that participants become more optimistic about variables on which they have direct influence, as compared to those variables that are subject to external forces (activation hypothesis).

intervention to analyze expectation convergence. Overall, we found support for the shared expectations hypothesis. Table 2 indicates that the SD was reduced in almost all cases, except for expected income increase from fishponds. We used Levene's test to identify whether the variances changed after the intervention, including the median modifications of the Brown-Forsythe test. The null hypothesis was moderately rejected for food expenditure ($P_{W0} > 0.056$; $P_{W50} > 0.055$; $P_{W10} > 0.066$), but not for any of the other items.

Another proxy variable supports the argument that collective action at the commune level was affected by the CLD mapping and simulation intervention. Participants judged it less likely that they would participate in the CIP again in their posttest survey (see Table 3). It may be that an empowerment effect related to self-organization possibilities creates pessimism about their individual and collective agency in the CIP. This argument could be supported by recent findings concerning the CIP in Cambodia (Plummer & Tritt, 2012), but the political-economic dimension of this needs further theorization in WEF nexus research (Foran, 2015). This is particularly relevant for local perceptions of provincial administration capacities for natural resources management, which has been recently devolved to provinces under D&D reforms (Vuković & Babović, 2018).

There is limited application of risk-based management in Cambodia with low availability and sharing of local risk information (Mochizuki et al., 2015), suggesting that it was our intervention that reduced uncertainty about sources of potential risk for our groups, though not uniformly, across variables.

4.3. Discussion—The Implications of Changes and Convergence in Expectations for Nexus Governance in Mekong

We set out to test the idea that reducing uncertainty and building consensus on action through participatory modeling could potentially catalyze new behaviors with this research. We hypothesized that participant expectations for (1) the likelihood of certain future events and (2) their own individual agency to respond to these events will change because of the CLD intervention. We also postulate that participatory modeling reduces uncertainty and enables convergence in expectations across members of the group.

Our expectations-testing results suggest that these ideas may be true in some interesting ways. The research team achieved a new understanding of WEF nexus risk anticipation in local stakeholders. We entered into

Table 3
Mean, Median, and SD Differences Across Groups With Regard to Changes in Expectations

	Mean			Median			SD_d		
Variable	G1	G2	G3	G1	G2	G3	G1	G2	G3
consistence: sunrise	−0.27	2.92	−0.10	0.00	0.00	0.00	−0.60	−2.02	0.01
consistence: river	−0.36	−2.17	0.27	0.00	0.00	0.00	−0.68	−1.60	−1.03
consistence: boy	0.00	0.00	0.09	0.00	0.00	0.00	−0.07	−0.20	−0.50
drought (5y)	0.20	−0.25	0.73	0.00	0.00	1.00	−0.39	−0.29	−0.43
drought (10y)	0.00	0.12	0.53	0.00	0.50	1.00	−0.31	−0.78	−1.16
takeover by child	0.40	0.19	1.47	0.00	0.00	1.00	−0.69	−0.04	−0.07
agr. income (5y)	1.07	0.25	1.67	1.00	0.00	1.00	−0.72	−0.71	−0.41
fish income (5y)	0.73	1.94	1.27	0.00	2.00	2.00	0.21	−0.07	−0.04
food expenditure (5y)	−0.67	−0.44	0.73	0.00	−0.50	0.00	−0.65	−1.00	−0.59
corn: earnings	1.60	0.38	−0.07	1.00	0.00	0.00	0.17	−0.53	0.02
corn: earn. with drought	−0.07	0.06	0.27	0.00	0.00	0.00	−0.34	0.29	−0.38
organic fert.: yield	0.20	−1.06	−0.13	1.00	0.00	−1.00	−0.20	−0.60	0.55
organic fert.: food quality	−0.40	−0.19	−0.80	0.00	0.00	−1.00	0.16	−1.24	0.22
fishpond: commune	−0.60	−0.31	−0.53	0.00	0.00	0.00	0.16	−0.57	0.63
fishpond: own	0.20	−0.12	−0.07	0.00	0.00	0.00	−0.49	−0.49	−0.56
fishpond: food quality	−0.67	−0.75	0.20	−1.00	−1.00	0.00	−0.62	−0.34	−0.05
fishpond: income	0.13	−0.44	0.20	0.00	−0.50	0.00	0.37	−0.02	0.29
irrigation pump: others	−0.53	−0.25	−1.13	0.00	0.00	0.00	0.71	−0.37	−0.36
irrigation pump: own	−0.20	0.00	1.53	0.00	0.00	0.00	−1.48	0.10	0.31
dam/dike commune	−0.80	0.69	0.93	0.00	0.00	1.00	0.63	−0.17	−0.90
dam/dike yield increase	0.60	0.19	−0.40	0.00	0.00	0.00	0.72	0.11	−0.58
CIP: participation	−0.33	−0.06	−0.60	0.00	0.00	0.00	0.24	−0.44	−0.15
CIP: income effects	−0.13	0.25	0.20	0.00	0.00	0.00	−0.33	−0.50	−0.63
CIP: own influence	0.27	0.12	0.07	0.00	0.00	0.00	−0.31	0.29	−0.31

Note. Mean and median values of the change are reported, while SD_d reports the difference in standard deviations before and after the intervention. $N = 15$ for G1 and G2 and $N = 16$ for G3. The table summarizes the results of differences in expectation changes across the groups (shared expectations hypothesis), with changes in standard deviations provided in the last three columns.

this work understanding that dams were at the heart of the WEF nexus in this region. Yet hydroelectric dam construction was not the primary risk identified for our participants. Local villagers consider themselves to be facing more immediate challenges to food security, like illegal fishing and locally degraded fish stocks, while dam developments are far-off concerns. Moreover, participants became significantly more optimistic concerning their individual agency to cope (i.e., increase agricultural and fishing income) in the face of such risks and, conversely, less enthusiastic about the likelihood that they will participate in their local upcoming CIP processes. The interpretation we offer is that the CIP results reflect the ongoing issue of the state's inability to provide communities' access to key resources for their development that the D&D reforms have been established to remedy. Local citizens participate in the CDP/CIP processes because there is no alternative. But if, as our results suggest, the sense of individual and collective agency is heightened, people will perhaps decide not to participate in the CIP. The convergence in expectations for multiple variables across the groups suggests that while collective solutions and institutionalized agreements are more likely to emerge, they are less likely to be realized through the CIP given expectations about reduced participation. Other community planning activities, both formal (e.g., Department of Agricultural Extension (DAE), 2012) and informal, may hold more promise for local WEF nexus governance.

Our evidence regarding the activation and convergence hypotheses is in line with previous studies from a wide range of application domains that evaluate the effectiveness of participatory system dynamics (e.g., Rouwette, 2003; Rouwette et al., 2011; Scott et al., 2016b). Those studies focused on more traditional settings for participatory modeling such as corporate or public policy applications in board room environments. The observed alignment of mental models seems to hold also in the context of groups at the community level with low formal educational background (convergence hypothesis). Similar to those of Rouwette (2003) and Rouwette et al. (2011), our participants became significantly more optimistic about individual opportunities under their control. While existing studies found no change in perceived behavioral control, our

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results point at an overall increase in the likelihood of individual as well as collective action. Future research will have to address the question whether these differences in outcomes are an artifact of somewhat different evaluation criteria used (perceived behavioral control versus expectations regarding future individual and collective action) or whether they are a function of either our participatory modeling protocol or the specific WEF nexus context in which we were operating.

Some caveats are important to interpreting our findings. In our experience, the CLD process generated discussion about other things than what were modeled, and so there is some leakage into issues and topics that were not controlled for in the process. For example, some expectation effects were observed for food quality from organic fertilizer use and related to aquaculture, which were not actually modeled in the CLD procedures. Secondly, differences across our groups were considerable. Table 3 provides differences across groups concerning median and mean changes in expectations. Although SD measures decreased across groups in most cases, there were differences across groups, and SD of some groups actually increased for several variables. This suggests that the development of shared expectations is by no means an unconditional result of the CLD intervention but is more likely contingent upon participants' contributions that are in turn influenced by internal group dynamics, or major external events, rather than intended intervention effects within the scope of the intervention protocol itself. Our cases were all treated on the same day in the same location with the same team, so we controlled for some influences; but participants did come from different communities, and group dynamics changed in each group with personalities. Finally, we can only say something about the uncertainties that we actually measured and cannot infer results for reducing uncertainties concerning variable coverage and model structure.

5. Conclusions

Our starting point in this paper was that two assumptions drive much participatory research in sustainability: that knowledge produced through participatory processes is more likely to identify transformational leverage points (Cash et al., 2003; Star & Griesemer, 1989) and that such knowledge and processes can directly and indirectly influence behavior change for sustainability (Gerritsen et al., 2013). Given the various issues for knowledge integration while engaging with values, power, and politics (Jordan et al., 2018; Miller & Wyborn, 2018; Wesselink et al., 2013), we argued that such assumptions need testing.

Our analysis contributes to explaining one possible mechanism of behavioral change resulting from systems thinking- and modeling-based interventions. Specifically, sustainability research suggests that participatory modeling can trigger self-efficacy outcomes and reduce perceived uncertainties in addressing collective action challenges. Our empirical results provide preliminary support for this claim and for a recent proposition in behavioral sciences that intervening to change expectations can drive changes in behavior.

Methodologically, we tested a novel evaluation framework for behavioral outcome evaluation in sustainability interventions. We measured positive and negative changes in expectations of participants in our procedure in line with the hypothesis that the participatory CLD mapping and simulation could affect their perceived self-efficacy (activation hypothesis). Our participants also demonstrated convergence in some key expectations about likelihood of future events and capacities to respond to these (shared expectations hypothesis). This is significant because reducing uncertainties at the group level removes some barriers impeding the complex adaptation among a large set of stakeholders with all the attendant uncertainties, politics, and power dynamics that WEF nexus governance demands. Our intervention effectively coproduced a new awareness of future individual and local shared risks that may follow global environmental change, regional and national energy strategies, and technical decisions on hydropower dam siting and design and ideas for potential responses to manage these in our case study participants, despite driver factors for the coming changes lying largely outside of local control. These results suggest three implications for participatory, model-based sustainability research and practice in general, and WEF nexus governance in specific.

The first significant point for designing participatory processes that are intended to generate governance outcomes is how updating participants' expectations does not rely on outputs produced and published after interventions. It appears to be at least as much about the process as the end product. The conceptual system interpretation and dynamic simulation in our CLD procedure changes some conditions (risk awareness and income expectations) that can affect future behavior of those participating during the 6-hr workshop process. This suggests a second insight on the importance of paying close attention to how expectations are being updated during the group activity in case these are wrong. For example, the individual increases in optimism for income in our groups are not in line with other findings on agricultural income expectations in Cambodia (Grafton et al., 2016; Scheidel et al., 2014). Not only did our intervention change expectations for the future, but it changed them in a way that could be risky for participants if they are wrong. The implication of this is that mechanisms to evaluate and navigate expectations updating, convergence, and divergence are needed during participatory modeling procedures, not afterward. The method we used could reduce the risk of unknowingly changing expectations against contradicting evidence while also supporting sustainability researchers to link their intervention and future potential behavior change impacts.

A third and final key insight for WEF nexus governance is that convergence and divergence in expectations point to clear areas of certainty and uncertainty in groups, which is critical to catalyzing opportunities and conditions for collective action. Group interpretation is an epistemic nudge, entailing deliberative processes of empowerment and so potentially strengthening agency and enabling collective action (John, 2018). This information can identify individuals primed for interventions, for example, technical training or further negotiations, on issues where uncertainty is a barrier. It also means that while heterogeneity in group modeling is advised to stimulate discourse, any participatory modeling exercise should carefully weigh advantages and disadvantages where collective action is the goal. In too homogenous groups, convergence may be achieved without surfacing and challenging assumptions. Conversely, groups too heterogeneous by design can produce unwarranted divergence in expectations, increasing uncertainty and reducing agreement.

One important caveat in our results is permanence of change and convergence in expectations. Structural power issues will undermine empowerment gains made in our process without further interventions. In this regard, future research could explore if different forms of research designs, participatory approaches, and group compositions have different effects on expectations, paying attention to power dynamics. Note that without a systematic experimental comparison of group compositions and intervention methods, the external validity of our findings remains limited and open to further analyses. Testing the effectiveness of different group selection procedures, including a random selection baseline, and their relation to participatory approaches, could increase external validity. For example, we chose an optimal demographic composition and group size, but future studies could experimentally test influence of group heterogeneity, leadership, group sizes, and many other variables on behavioral effects of CLD interventions, or any other workshop technique or epistemic approach.

We conclude that participatory CLD mapping and simulation is likely to be one effective implementation method for WEF nexus governance processes. We also conclude that expectations measures can be used, with caution, to evaluate the likelihood of future behavioral change following participatory processes. Our contribution lies in developing and testing one mechanism for measuring changes in expectations and showing that it can be done in challenging field conditions.

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