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Integrating Values to Improve the Relevance of Climate-Risk Research

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Key Points:

- Assessing risk-management strategies inherently imposes a value perspective on climate research
- We suggest assessing potential outcomes of strategy implementation from the perspective(s) of those potentially affected
- We propose a qualitative framework and workflow for building stakeholders' values into scientific assessment of impacts and outcomes

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract Climate risks are growing. Research is increasingly important to inform the design of risk-management strategies. Assessing such strategies necessarily brings values into research. But the values assumed within research (often only implicitly) may not align with those of stakeholders and decision makers. These misalignments are often invisible to researchers and can severely limit research relevance or lead to inappropriate policy advice. Aligning strategy assessments with stakeholders' values requires a holistic approach to research design that is oriented around those values from the start. Integrating values into research in this way requires collaboration with stakeholders, integration across disciplines, and attention to all aspects of research design. Here we describe and demonstrate a qualitative conceptual tool called a *values-informed mental model* (ViMM) to support such values-centered research design. ViMMs map stakeholders' values onto a conceptual model of a study system to visualize the intersection of those values with coupled natural-human system dynamics. Through this mapping, ViMMs integrate inputs from diverse collaborators to support the design of research that assesses risk-management strategies in light of stakeholders' values. We define a visual language for ViMMs, describe accompanying practices and workflows, and present an illustrative application to the case of flood-risk management in a small community along the Susquehanna river in the Northeast United States.

Plain Language Summary Individuals, organizations, businesses, and governments face difficult choices about how to adapt to the changing climate. Research can help by, for example, providing insights about future climate conditions or showing how potential courses of action may play out under those conditions. But like all decisions, climate adaptation decisions are fundamentally driven by values. What do people want to achieve through adaptation? There are many answers to this question, and different people may care about different things. Research that evaluates possible adaptation outcomes on grounds different from what people actually care about may be useless or even harmful. To design good research on adaptation strategies, we need to collaborate with stakeholders, communicate across disciplines, and strike the right balance with practical limitations on time, resources, and scientific feasibility. In this article, we present a framework for designing climate-risk research that looks at policy options from the perspective of stakeholders by focusing on aspects of the potential outcomes that matter to those stakeholders. A key component of the approach is collaborative system diagramming to build shared understanding of the problem and relevant science. A second component is careful review of interviews or focus groups to identify stakeholders' values and make clear how those values intersect with the study system and any scientific modeling of that system. We demonstrate the approach using an example about flood risk.

1. Introduction

As the impacts and risks of climate change continue to grow (IPCC, 2022), there is an urgent need to expand and prioritize research related to *managing* climate risks (NASEM, 2021a). Such research goes beyond the characterization of hazard, vulnerability, and risk by *assessing strategies for managing those risks* (Keller et al., 2021). This step requires a shift in the role of human values in research. Research on managing climate risks must, by its nature, employ some means of judging the desirability of potential futures. One cannot assess strategies (also called measures, actions, responses, options, or alternatives) without taking a perspective on what makes one outcome better than another. Taking such a perspective puts values in an explicitly *normative* role.

Whose values should play this role? One approach is to judge outcomes from the perspective(s) of those potentially affected by the climate impacts and strategies under assessment. For simplicity, we refer to these potentially affected people as *stakeholders*—acknowledging that broader definitions of the term are in use (Figure S1 in Supporting Information S1) and that *rightsholder* is more apt in some cases (Darling et al., 2023). Studies investigating stakeholder values around climate risks and management strategies reveal a rich diversity of perspectives and considerations (e.g., Adger et al., 2022; D. L. Bessette et al., 2017; Graham et al., 2013; Meo et al., 2021; Quinn et al., 2023). In contrast, studies that assess strategies typically consider only a narrow range of economic metrics (Adger et al., 2011, 2022; Graham et al., 2013; Quinn et al., 2023), leading to calls for a *values-based approach* to climate adaptation (O'Brien & Wolf, 2010b) and the study of climate change and loss *as if people mattered* (Tschakert et al., 2017).

Assessing outcomes in light of stakeholder values requires centering research designs around values and prioritizing responsiveness to those values in the give-and-take among design considerations such as scientific feasibility and limitations on time and resources. To support such research designs, we adopt and reformulate the concept of *values-informed mental models* (ViMMs) (D. L. Bessette et al., 2017; Mayer et al., 2017). Analogous to positioning stakeholder values on landscape maps (Brown, 2006; Novaczek et al., 2011), ViMMs position values within a conceptual model of a study system to visualize how that system may impact what stakeholders care about. The ViMM framework provides a medium for structuring and synthesizing inputs from both researchers and stakeholders. The resulting products and insights can support values-centered design of research that assesses strategies for responding to climate risks.

Constructing and using ViMMs can involve collaboration in line with the overlapping concepts of transdisciplinary (Holzer et al., 2018), participatory (Salter et al., 2010; Voinov et al., 2018), and co-production (Norström et al., 2020). Co-production is an increasingly common framing in climate adaptation research, yet evidence for the benefits of co-production is limited (Jagannathan et al., 2020; Lemos et al., 2018; Wyborn et al., 2019) and published best practices prioritize high-level principles and general themes over "nuts and bolts" (Clifford et al., 2023). Here we supplement high-level principles with specific approaches to structuring interactions with stakeholder partners in service of framing climate-risk studies around the values of stakeholders.

Inclusive engagement with a range of stakeholders (Colvin et al., 2016; Herb & Auermuller, 2020) is a key challenge for any collaboration framework and one that we address only tangentially here. Methods described here will not, on their own, ensure inclusive engagement. Our focus is how to digest and use what is learned through such engagements so that the resulting assessment will be relevant and inclusive with respect to all those engaged. Specifically, we address the task of incorporating stakeholder values in the normative role of characterizing desirable outcomes within studies that assess strategies for managing climate risks.

2. What We Mean by "Values"

To begin, we clarify our use of the word "values" and situate it with respect to different disciplinary vocabularies. By "values," we refer to all that matters to people (Keeney, 1992; Tschakert et al., 2017). This usage follows the standard beliefs/values dichotomy in decision analysis (Clemen, 1996; Keeney, 1992) and aligns with divisions labeled elsewhere as beliefs/desires (psychology, cognitive science, philosophy) (Bratman, 1987), beliefs/tastes (economics) (Gilboa et al., 2004), and facts/values (philosophy) (Foot, 2005; Putnam, 2016). Each of these divisions separates values from beliefs. Beliefs concern how the world works and they can be factually correct or incorrect. Values concern how one desires the world to be, and they can serve as grounds for preference and choice.

On the values side of the beliefs–values divide, there are many approaches to conceptualizing values and valuing (Graham et al., 2013; Jones et al., 2016; Rawluk et al., 2019; Tschakert et al., 2017). Approaches tend to vary by discipline. For example, some areas of study concerned with predicting and influencing human behavior use a cognitive hierarchy model (Fulton et al., 1996; Homer & Kahle, 1988) that reserves the term *values* for only the most stable and fundamental antecedents to behavior. Broader approaches recognize both *held values* and *things valued* (Tschakert et al., 2017). Held values are abstract ideals or principles such as autonomy and fairness. Things valued are specific objects or experiences such as one's home or visiting with grandchildren. (The relation between held values and things valued need not be direct or formulaic.) Other terminology includes *lived values* (an emphasis on people's lives and places) (Graham et al., 2013) and *human values* (in contrast to economic valuation) (Corner et al., 2014).

Here we take an inclusive approach to conceptualizations of values and valuing. To expand the integration of values into strategy assessment, stakeholder interactions should be approached with an expansive view of what values are and how they might be expressed. We therefore suggest using whatever conceptualizations make it easiest to recognize and document the breadth of potentially impacted values (see *mapping values* below). Indeed, drawing on multiple conceptualizations or categories of values may help broaden the scope of whose values can be elicited and recognized. Examples include studies of the *epistemic* and *ethical* values of climate-risk researchers (in potential contrast to stakeholders) (Mayer et al., 2017) and of the *lived* and *landscape* values of residents versus visitors in coastal areas threatened by sea-level rise (Meo et al., 2021).

Regardless of initial conceptualization, values must be further structured for integration into strategy assessment (R. S. Gregory, 2017; Keeney, 1992). We propose ViMMs as an appropriate structuring framework in light of challenges common to the climate-risk context. One such challenge is that—like many public policy actions (Lindblom, 1959) adaptation strategies can affect diverse groups of people with heterogeneous values (O'Brien & Wolf, 2010a; Tschakert et al., 2017). A key task for climate-risk research is to illuminate synergies and trade-offs among contested and potentially competing values (Adger et al., 2009; Garner et al., 2016; Keller et al., 2021). This task suggests what is sometimes called an a posteriori approach to decision analysis (Garner et al., 2016; Herman et al., 2015) based on the concept of Pareto optimality among multiple, *disaggregated* objectives (Garner et al., 2016; Keller et al., 2021). Such analyses refrain from assumptions about relative priority among multiple salient values and have no need for approaches to eliciting and modeling associated weighting schemes. By forgoing a single composite value function, such analyses enable the use of stakeholder-relevant metrics (D. Bessette & Gregory, 2020) and allow disparate value considerations to remain incommensurable within a quantitative analysis.

3. A Tangle of Challenges

Integrating stakeholder values into climate-risk research faces special challenges that arise from the characteristics of climate risk, the types of analyses needed, and the makeup of teams capable of performing the often complex research. We introduce these challenges in order to articulate the needs that ViMMs address. One important challenge has already been broached above: the broad range of people, with diverse values and worldviews, that are potentially affected by climate impacts and response strategies. Additional challenges result less from features of stakeholders and their values and more from features of the research into which those values are to be integrated. In other words, integrating values into climate-risk research is hard because climate-risk research is already difficult and the challenges interact. We highlight three of these challenges in turn.

First, questions about how to adapt to a changing climate are often "wicked problems" (Moser et al., 2012; Rittel & Webber, 1973) in that (among other features) their scope has few natural boundaries, putting out of reach any single, comprehensive problem formulation. Problem formulation involves subjective judgments and is inseparable from conceptions of who is a stakeholder. Further research-design choices such as modeling frameworks, processes included or neglected, and the scale and resolution of a study are inseparable from choices about which and whose values can be reflected in resulting strategy assessments. Stakeholder values must therefore be considered holistically and from the beginning as an integral part of navigating the many trade-offs involved in research design.

Second, in the climate-risk setting, uncertainties that influence strategy success are deep and dynamic (Keller et al., 2021). Such hard-to-characterize uncertainties add to wickedness (Kwakkel et al., 2016) and motivate methods that depart from traditional expected-utility analysis (Keller et al., 2021; Marchau et al., 2019). Methods of analysis for decisions under deep uncertainty (DMDU) (Marchau et al., 2019) can be computationally intensive, which in turn constrains other research choices such as model scope and resolution (Vezér et al., 2018). Moreover, feasible analyses typically neglect some sources of uncertainty while prioritizing others; but which uncertainties are most consequential is always relative to the choice of outcome metric. In this way, the presence of deep and dynamic uncertainties further reinforces a need for holistic research design centered around an understanding of the values driving outcome assessment.

Third and finally, assessing adaptation strategies often involves the study of complex, coupled natural-human systems comprising diverse processes and scales. As a result, such research requires multidisciplinary teams and integration across disciplines. But interdisciplinary integration is notoriously vexing. Members of appropriately diverse research teams can struggle to adequately understand one another's methods and perspectives. Disparate, discipline-based reward structures can further hamper collaboration and collectively pull research priorities away from the needs of real-world partners. Investigating stakeholder values may require even greater disciplinary breadth, amplifying these difficulties. Approaches to integrating values are more likely to succeed if they acknowledge and address the interdisciplinary nature of the research into which those values are to be integrated.

4. The Insufficiency of Traditional Tools

While integrating values into analysis may be new to many academic researchers, inspiration can be drawn from the applied field of decision analysis. Decision analysts traditionally work with clients to clarify and characterize the clients' values before defining the decision problem around those values and then analyzing alternative courses of action. Academic researchers assessing potential responses to climate risks are similarly engaged in a form of decision analysis. They too must define the problem to be analyzed, and they can do so based on an understanding of stakeholders' values. Yet established decision-analysis frameworks (Clemen, 1996; Keeney, 1992) and best practices built around them (R. Gregory et al., 2012) are, we argue, insufficient for structuring such analyses in the climate-risk setting. We briefly indicate what these traditional structuring tools are and why their usefulness may be limited in this setting. Parenthetical comments below link some shortcomings to specific challenges discussed above (diverse values, wicked problems, deep uncertainties, and complex systems).

Established tools for structuring decision analyses include values hierarchies, means-ends diagrams, influence diagrams, and decision trees (Clemen, 1996; R. Gregory et al., 2012). *Values hierarchies* (Keeney, 1992) organize decision makers' goals into a nested, groups-within-groups structure. They aid systematic reflection on values and facilitate mathematization of those values in a utility function. Values hierarchies may continue to be helpful in the climate-risk setting, with three caveats. First, practices for their elicitation are complicated by the diversity and diffusion of stakeholders (diverse values). Second, their function as a precursor to overall utility calculations is largely unnecessary (diverse values). And third, more domain-specific frameworks for organizing values (references below) may be of equal or greater use as starting points in climate-risk settings.

Means-ends diagrams (Keeney, 1992) connect end goals with proximate means for achieving them via arrows representing causation. Constructing such diagrams can help decision makers identify means to valued outcomes and disentangle such means (of merely instrumental importance) from the valued outcomes themselves. Means-ends diagrams may continue to be useful in the climate-risk setting, with two caveats. First, with diverse and differentially affected stakeholders (diverse values), a valued outcome may be intrinsically important for one person and merely a means to an end for another (Lindblom, 1959). Second, in complex coupled systems (complex systems), identifying immediate causal precursors to valued outcomes may, on its own, go only a short ways toward tracing promising causal paths from those outcomes back to potential strategies. Adequate understanding of causal pathways may require deep integration of subject-area knowledge from diverse disciplines.

Influence diagrams and decision trees are closely related diagramming forms (Clemen, 1996). *Decision trees* map the potential outcomes of a set of choices in preparation for expected benefit calculations. Such calculations are incongruous with the climate-risk setting both because their treatment of uncertainty departs from best practices for DMDU (deep uncertainties) and their treatment of values (use of a single overall value function) hinders the goal of revealing and clarifying trade-offs among multiple value perspectives (diverse values). *Influence diagrams* are a simpler and more intuitive "front end" for decision trees and expected utility calculations (Shachter, 1986). They traditionally serve as a boundary object between analysts and decision makers (Pearl, 2005; Shachter, 1988). Influence diagrams are inapt for the climate-risk setting insofar as their function is the design of a type of analysis poorly suited to that setting.

Some researchers may still find influence diagrams heuristically useful for design of climate-risk analyses, though a loosely analogous form better suited to best-practice DMDU analyses is the XLRM diagram (Lempert et al., 2003). In any case, neither fills the need addressed by ViMMs. Both forms provide a high-level summary of the shape and scope of a proposed analysis. As such, both can be used to sketch out and deliberate over alternative problem formulations, including the ways that values are operationalized within them. But these forms ignore and obscure what is *left out* of a given problem formulation. They neglect and conceal any values that have not yet been quantitatively operationalized. And they abstract away from underlying processes connecting strategies to outcomes. As a result, these diagramming forms do little to facilitate interdisciplinary understanding of underlying processes, to support collaborative and holistic decisions about study scope, or to facilitate recognition and structuring of stakeholder values that they might be integrated into analyses.

5. The Game Plan of ViMMs

Before going into details, we explain at an abstract level the basic approach that ViMMs implement and the rationale behind that approach. In broad strokes, there are two steps to constructing ViMMs. The first step is to develop a shared mental model of the study system. A *mental model* is an internal mental conception of some part of the external world (Craik, 1952; Johnson-Laird, 1983). Researchers use a variety of representation formats to externalize and document individual mental models (J. D. Sterman, 2008) as well as shared or collective ones (Abel et al., 1998; Jones et al., 2011). In developing ViMMs, we express mental models through a boxes-and-arrows diagram form sometimes called a *conceptual model* and often used to collaboratively build shared understanding of complex systems (Badham et al., 2019; Barbrook-Johnson & Penn, 2022; Heemskerk et al., 2003; Longstaff et al., 2010).

The mental model should include relevant climate hazards and their drivers, potential actions by decision makers, potential consequences for stakeholders, and processes that connect these elements. Importantly, the model should be broader in scope (in terms of processes, consequences, and actions) than any subsequent strategy assessments anticipated by researchers. Participants in mental-model development can include site-specific experts such as decision makers, practitioners, or highly engaged stakeholders. The process requires iteration and sustained collaboration to integrate knowledge spread across participants. While the scope and emphasis of the resulting mental model will implicitly reflect the values of participants, the product remains a statement of shared *beliefs* about how the study system functions.

The second step is to engage a broader swath of (possibly less engaged) stakeholders in discussions about potential climate impacts and decision consequences with a focus on why those impacts matter. We study transcripts of these interactions to identify values expressed by participants. We use a simple and flexible extension to the visual language of conceptual models to visually map each expression of values to nodes in the model where those values may be most concretely instantiated within the depicted system. Importantly, this mapping process is compatible with recognizing both held values and things valued as well as both concrete and intangible values (Section 2). This mapping takes the first steps toward operationalizing or otherwise meaningfully incorporating such values within strategy assessments. While recognizing and structuring values, the resulting visualization retains a clear separation of values from beliefs.

Key points in the rationale for steps sketched above include the following. Collaborative development of the shared mental model frontloads initial integration and shared understanding across the perspectives and disciplines of participants. Mapping stakeholders' values onto the resulting diagram contextualizes those values within the shared mental model already established among the research team. The flexibility of the mapping procedure removes barriers to the recognition of values that may initially be challenging to operationalize. The resulting ViMM provides a shared visual scaffold supporting holistic research design for strategy assessments in which choices about the values to be recognized are inseparable from other scientific, technical, and practical design considerations.

6. A Visual Language for ViMMs

Developing the mental model and mapping stakeholders' values require an appropriate visual language. Many diagram forms exist as starting points, but none appear to have all the right features. A key fault line among diagram forms divides those representing *discrete events* from those representing *system dynamics* (J. S. Morgan et al., 2017). Influence diagrams (Howard & Matheson, 1984) (see above) are an example of discrete-events diagramming, representing decision points, contingencies, and payoffs as a sequence of events ordered in time. Bayesian networks (Pearl, 1986) and other directed acyclic graphs (Pearl, 1995) also use the discrete-events approach. Such diagram forms are poorly suited for visualizing the feedbacks characteristic of coupled systems,

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and their fixed time horizons prejudge aspects of problem framing that are better left open by a visualization meant to support research design.

In contrast, systems-dynamics diagrams depict generalized knowledge of system behavior through a representative set of state variables and their interactions. Examples include causal-loop diagrams (J. D. Sterman, 2000), fuzzy cognitive maps (Gray et al., 2015; Kosko, 1986), stock-and-flow diagrams (Meadows & Wright, 2008), and conceptual models (Heemskerk et al., 2003). We follow this system-dynamics approach as it allows for feedbacks and depicts systems without prematurely imposing a sequence for potential decisions or time horizon for outcome evaluation. Many of these diagramming forms add edge annotations indicating the sign or magnitude of influence and as a result can allow only scalar-variable nodes. Because this restriction can hamper concise representation of complex systems, we follow (some) conceptual models by forgoing edge annotations and allowing multivariate and categorical variables.

Strategies for managing climate risks often consist of a portfolio of actions taken in concert (Keller et al., 2021). These component actions may intervene at different leverage points in a system and must therefore be represented separately in a causal diagram. We represent available component actions as *levers* (following the XLRM nomenclature (Lempert et al., 2003)), each pointing at the part of the system they influence most directly. Because available levers may differ from one decision maker to another, resulting figures represent agency in the system with respect to a specific decision-making agent (individual or body).

Existing system-dynamics visualizations can represent values in only a limited way. Nodes of causal-loop diagrams and fuzzy cognitive maps are sometimes annotated with preferences for a specific state or trend (e.g., high, low, increasing, decreasing) (Desthieux et al., 2010). These preferences express values—but only through the narrow lens of the scalar state variables in the diagram. Such preferences can directly express only things valued (not held values) and only quantifiable aspects of those valued things. While scalar metrics are ultimately needed for quantitative analysis, a framework meant to support translation of values into metrics should not exclude or minimize values that cannot immediately be expressed in such narrow terms. Much of what people care about is more naturally expressed in terms of held or abstract values (Tschakert et al., 2017); and even valued things may be experiential, intangible, or otherwise challenging to quantify directly (Satterfield et al., 2013; Tschakert et al., 2017).

To represent and map values, we annotate nodes of the conceptual model with *values tags* that use keywords to flexibly indicate a value perspective from which system behavior can be subjectively appraised. Keywords can address held values or things valued. Placement of tags indicates system variables whose states are the subject of concern. In combination with the relaxed node definition (above), this approach allows for the summary and partial structuring of a broad range of stakeholder values, each tagged to relevant components of the conceptual model.

7. Example Workflow and Application

The visual language introduced above can be applied in several ways. In principle, the mental model of the study system (expressed in the form of a conceptual model) can be that of an individual or a group. Similarly, the value tags can collate inputs from one person or (as per the rationale above) from many. The process of constructing ViMMs will vary depending on these choices. The process may also vary to accommodate available personnel time, desired level of rigor, and degree of integration across parties to the collaboration. Many workflows are possible. Here, we outline one specific workflow as an illustration (Figure 1). But first, we briefly introduce the case study location from which the illustration is drawn.

The example below is drawn from the work of the Penn State Initiative for Resilient Communities (PSIRC)—a transdisciplinary project "addressing local resilience challenges in riverine communities vulnerable to flood risk." The project's pilot study took place in Selinsgrove, Pennsylvania, a small community (population ~6,000) along the Susquehanna River in the Chesapeake Bay Watershed. The community faces flood risk from the Susquehanna River and from flash flooding in small creeks and streams. These risks are evolving due to changes in climate and land use. At the same time, residents face the possibility of increasing insurance premiums as the Federal Emergency Management Agency (FEMA) introduces a revised flood insurance rate formula in an effort to reform the deeply indebted National Flood Insurance Program (NFIP).

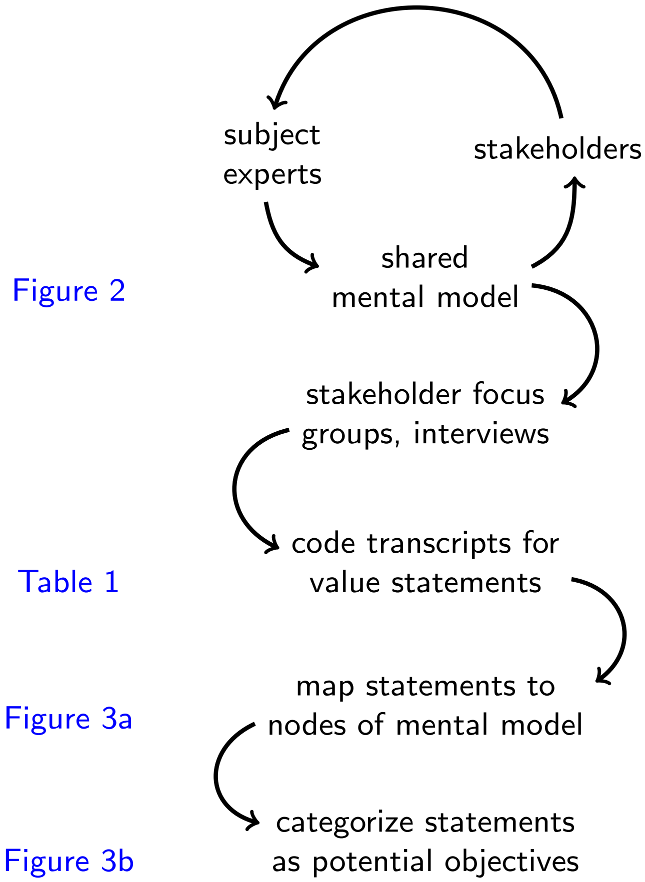

Figure 1. A high-level flow chart depicting a workflow for constructing values-informed mental models (ViMMs). Blue text on the left refers to figures and tables illustrating specific stages of the workflow.

In the first stage of the illustrative workflow, a team synthesizes a consensus mental model of the study system and available decision levers. The process is informal (talking, drawing, and revising)—analogous to the development of "expert" mental models for a variety of applications (G. M. Morgan et al., 2002). The aim is not to document differences between individual mental models but to informally bring such differences to the surface and shepherd participants toward a shared understanding. Iterative convergence on the consensus model instantiates a number of processes that can benefit team integration, including collaborative model building (Badham et al., 2019; Heemskerk et al., 2003), problem structuring (Eden, 1994), conceptual clarification (Eigenbrode et al., 2007), knowledge engineering (Beers & Bots, 2009), and standardization of language (Siqueiros García et al., 2019). The resulting figures begin to externalize and integrate knowledge that is initially spread across the diverse teams needed for climate-risk research (Keller et al., 2021).

In the case study, the consensus mental model was developed as follows. The research team attended a series of local meetings and tours followed by a facilitated workshop to scope community flooding impacts in Selinsgrove (Iulo et al., 2020). Participants included local residents, officials, decision makers, and practitioners (e.g., insurance agents, floodproofing contractors, non-governmental organizations). Eight members of the multi-disciplinary research team then independently drafted mental models of the study system, each integrating their disciplinary expertise with the preceding on-the-ground experience. One member synthesized these into a proposed consensus model, and the research team discussed and critiqued that model across five iterations. The team then discussed this consensus model with roughly fifteen previously engaged local partners, who critiqued, confirmed, and proposed changes to the diagram. Figure 2 shows a simplified version of the resulting mental model.

A second stage of the workflow prioritizes discussion of how stakeholders are or may be affected by climate impacts or by the use of available levers. Useful formats for this stage include focus groups and interviews. Whatever the format, we recommend recording and transcribing discussions for careful analysis. In the illustrative case study, we conducted interviews with residents, community leaders, and practitioners, followed by focus groups with flood-risk management professionals and additional residents. (Cooper et al. (2022) reports findings from the resident interviews, while the illustrative, fictionalized statements in Table 1 reflect sentiments expressed across the suite of interviews and focus groups.)

To process data from interviews or focus groups, transcript coders (Saldana, 2015) first identify statements expressing stakeholder preferences or attitudes about potential risk-management outcomes (Table 1). Each of these evaluative statements identifies a way in which system dynamics intersect the speaker's values. Coders then map each statement onto a specific node of the mental model (Figure 3a). The guiding heuristic is to identify the part of the system that would need to be measured in order to quantify what matters to the speaker in the given statement. (If there is no such node in the mental model as drawn, the statement is mapped to whatever node is the closest causal precursor to the required measurement.) The mapping exercise bridges knowledge and values from multiple partners to a collaborative process. The results may prompt further development of the underlying mental model, in particular where stakeholders' evaluative statements correspond to processes causally downstream from, or otherwise poorly represented in, existing system components in the model.

Where further aggregation and summary is helpful, the list of evaluative statements can be divided into categories (Figure 3b). The guiding heuristic is to lump concerns that can be characterized on a common scale or may be considered substitutable (Ayres et al., 1998). Conversely, split concerns that stakeholders may consider ethically incommensurable (Hsieh & Andersson, 2021). Frameworks for recognizing and categorizing values can be drawn from a number of sources (Tschakert et al., 2017), including systems of cultural (Satterfield et al., 2013) and environmental (Tadaki et al., 2017) valuation, feminist (Moosa & Tuana, 2014) and indigenous (Dockry

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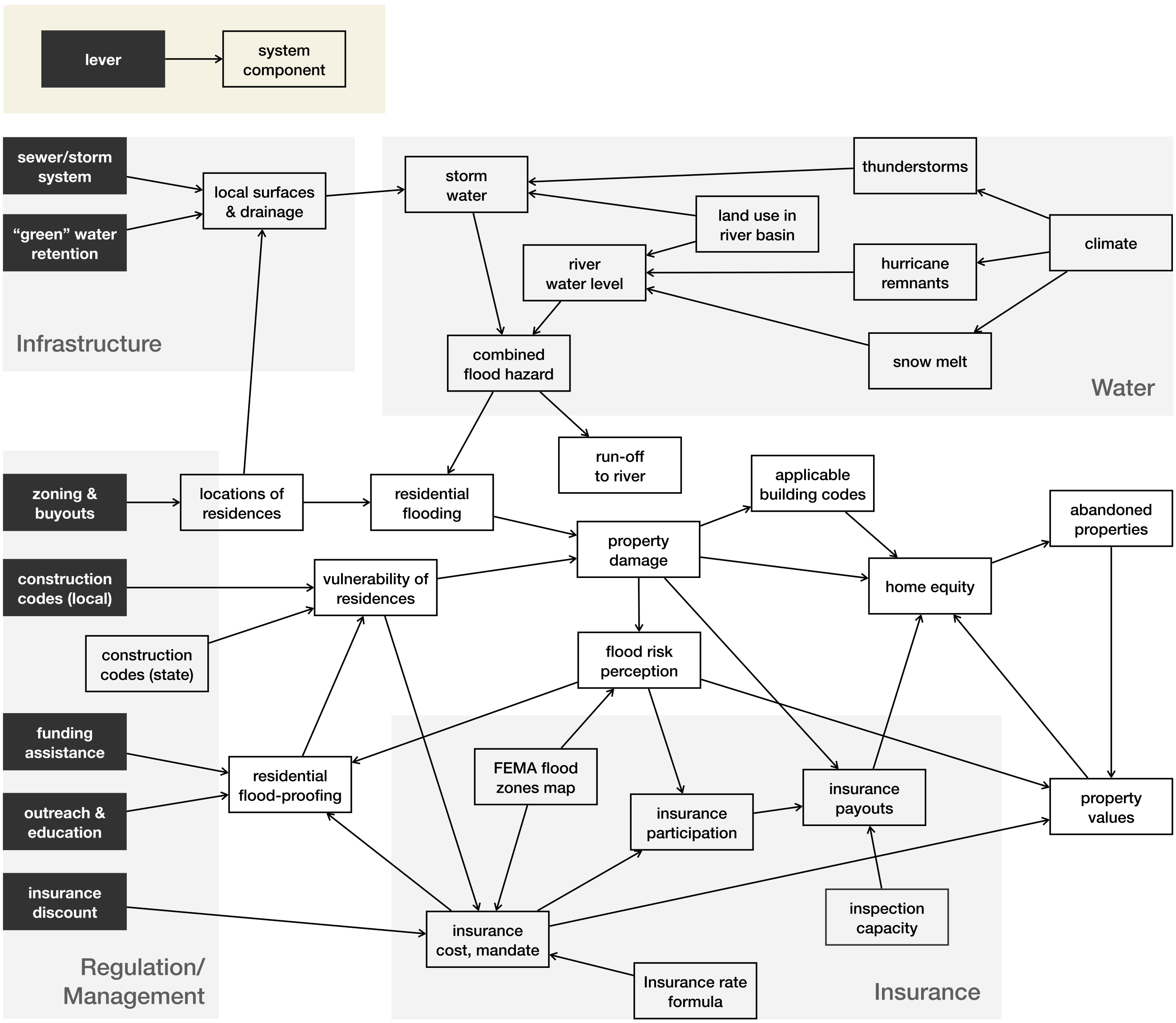

Figure 2. An illustrative consensus mental model representing one stage in the construction of a values-informed mental model (ViMM). The example addresses inland flood risk in a small riverine town, inspired by ongoing research on flood risk along the Susquehanna River in the United States. Levers are those available to community-level planners. See Table S1 in Supporting Information S1 for node descriptions.

et al., 2016) perspectives, and inventories specific to places (Raymond et al., 2010), landscapes (Brown & Reed, 2000), hazards (Adger et al., 2022; Graham et al., 2013; Quinn et al., 2023), or intangible values (Tschakert et al., 2019). In ongoing work, we have categorized evaluative statements via a consensus process among multiple transcript coders, but this step could also provide an opportunity to deepen co-production by involving local partners in the categorization exercise.

8. Using ViMMs to Design Strategy Assessment

Research design involves choices. In the case of research on strategies for managing climate risk, choices include which strategies to evaluate, which uncertainties to explore, at what time scale to project outcomes, and with what metrics to characterize those outcomes (Keller et al., 2021). (Note that "metric" is used with a different meaning in studies that characterize climate hazards (e.g., Jagannathan et al., 2021)) More technical matters include choices about scientific models and linkages, data sources, and statistical methods (Keller et al., 2021; Vezér et al., 2018). ViMMs offer a foundation for making these research design choices more collaboratively and holistically. And by

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Table 1
Illustrative Evaluative Statements (Fictionalized but Inspired by Reality) of the Type Identified During the Process of Constructing a Values-Informed Mental Model (ViMM)

#	Example statement	Value bin
1	People just walk away from their homes and stop paying taxes on the property.	Borough finance
2	We're river people. My grandparents built this house, and I've lived here my whole life.	Sense of place
3	Cleanup and repairs cost a lot more than I would have expected from just a few inches of water.	Personal finance
4	We need to be doing our part to improve water quality in the river and downstream in Chesapeake Bay.	Protect environment
5	I look out my window every morning at the river and I think this is paradise.	Beauty/aesthetics
6	We were living with this mildew for months, which can't be good for you.	Health and safety
7	The downside of buyouts is that they reduce future tax revenue for the borough.	Borough finance
8	These derelict properties in the neighborhood are an eyesore for everybody.	Beauty/aesthetics
9	You add the cost of repairs to what you still owe on the mortgage, and it might be more than the house is worth. It's a terrible situation to be in.	Personal finance
10	My elderly father lives with us, and being cut off from care and medical supplies for just a few days is a risk.	Health and safety

Note. Numbers in the left column are used in Figure 3a. Entries in the right column are used in Figure 3b. Statements inspired by ongoing research on flood risk along the Susquehanna River in the United States (Cooper et al., 2022; Iulo et al., 2020).

orienting collective expertise around *why the problem matters*, ViMMs foreground relevance and inclusivity with respect to stakeholder values as critical design considerations.

Defining strategy-performance metrics is the design choice most proximate to stakeholder values. Each tag (Figure 3) indicates a way in which potential outcomes matter to people. Strategy performance should be

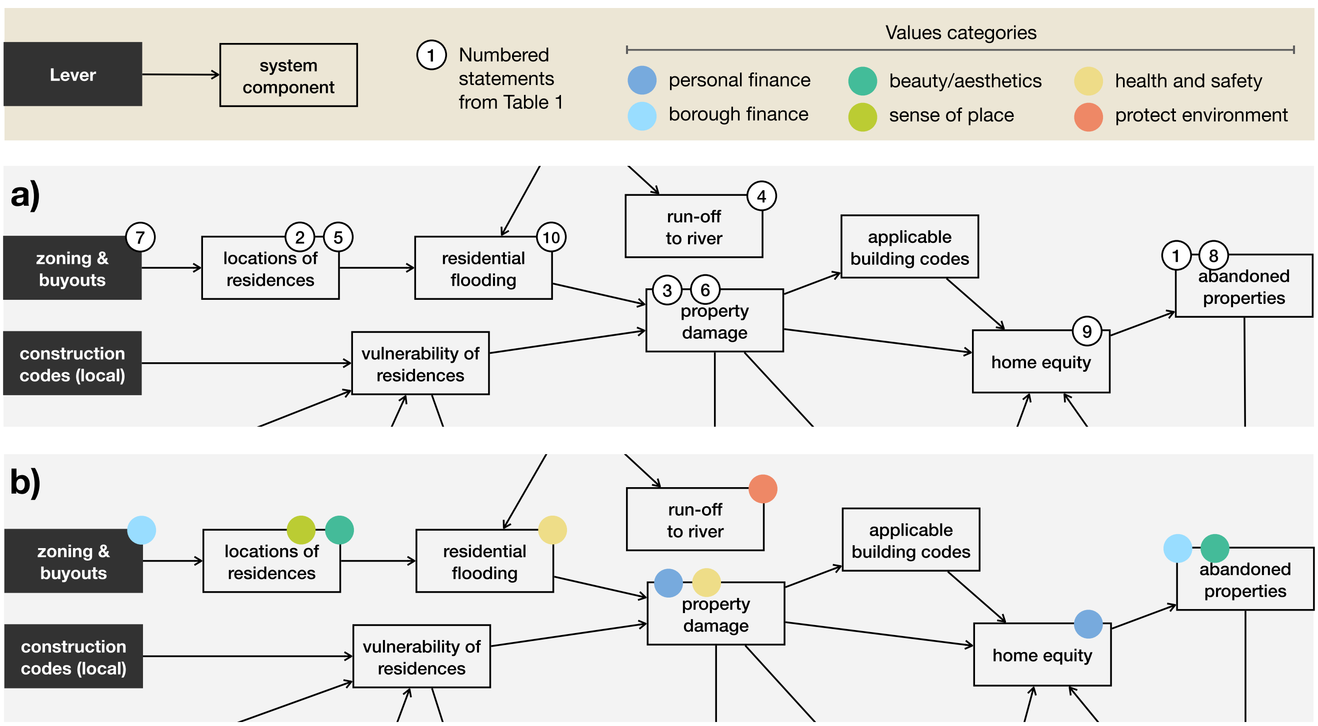

Figure 3. (a) An excerpt of the mental model shown in Figure 2 illustrating the mapping of evaluative statements (Table 1) onto a consensus model to construct a values-informed mental model (ViMM). (b) The same excerpt, now with the mapped evaluative statements categorized for a more succinct visual summary.

characterized using metrics that operationalize, or serve as informative proxies for, these value considerations (D. Bessette & Gregory, 2020; Garner et al., 2016). ViMMs synthesize key inputs to support deliberation about appropriate metrics. The consensus mental model may also be refined or expanded through such deliberation and value tags repositioned more precisely. Ultimately, the limited number of metrics that can be included in any one analysis may be insufficient to summarize all expressed values. The accounting of values provided by ViMMs can aid deliberations about which to prioritize for inclusion as well as guiding communication of caveats and limitations to the relevance and inclusiveness of the resulting analysis.

Many other research-design decisions can be informed by stakeholder values and are linked with the choice of metrics. Available metrics are constrained by the scale and resolution at which tagged system components will be modeled (Jagannathan et al., 2021; Vezér et al., 2018). Levers should be aligned with values in the sense of including in the analysis levers that are promising means of influencing the chosen metrics (Keeney, 1992; Vezér et al., 2018). Chains of causal influence informally mapped in the mental model suggest which system components must be modeled and coupled in order to link levers all the way to metrics. Outcome metrics can also shape the treatment of uncertainties by driving risk-based calibration of models (Pappenberger et al., 2007), vulnerability analyses to discover which scenarios lead to the worst outcomes (Bryant & Lempert, 2010), and sensitivity analyses to discover where more research is needed to reduce uncertainty about those outcomes (Wong & Keller, 2017).

Any given study can include only a subset of the levers and components that would constitute a (mythical) perfect and complete analysis. Moreover, the perceived boundaries of open, coupled systems are famously subjective (Rittel & Webber, 1973). The visual language of ViMMs offers a medium for mapping out a relatively expansive vision of a study system (e.g., Figure 2) before deliberating over which components can be included in a tractable analysis.

ViMMs structure and represent values expressed during a given period of engagement. But stakeholders' values, and perceptions of salience, may evolve over time—including through participation in research collaborations. Values are rarely entirely fixed, and iterative engagement over longer-term collaborations may reveal change that could, in turn, inform future research designs.

9. Discussion

We have proposed a diagramming practice and illustrative workflow to support the incorporation of stakeholder values into the normative, outcome-evaluation role in research that assesses strategies for managing climate risks. Values-informed mental models (ViMMs) integrate inputs from diverse collaborators to support the design of relevant and inclusive research that assesses strategies in light of stakeholders' values.

Based on our experience in academic research, we anticipate unease among some readers—not with the methods we propose but with the very task we address. Some researchers may be unaccustomed to thinking about values within research design or wary of breaking perceived taboos against normative judgments in science (Steel et al., 2017). In the face of encouragement and guidance on incorporating stakeholder values into research, it may be tempting to instead retreat into familiar disciplinary lanes and try sticking to the facts.

But this only-the-facts option is a mirage. Assessing potential courses of action is a fundamentally values-based activity (Clemen, 1996; Keeney, 1992). The alternative to explicitly discussing the normative side of assessment is not neutrality about values but opacity and confusion. Where strategy assessment lacks clear discussion of motivating values and their influence on study design, decision makers would be right to view findings with some skepticism, asking "Whose interests does this assessment reflect?"

The climate change research community increasingly recognizes the roles that social and ethical values play in shaping and framing research in even *the physical science basis* of climate change (Pulkkinen et al., 2022). Using science to assess strategies for managing climate risks necessarily pulls such values from a supporting role to a starring role—directly co-determining the findings of strategy assessments.

We have only provisionally resolved the question of *whose values*. In our ethical judgment, assessing potential outcomes from the perspective of those most affected by the risks and strategies in question is a defensible default for climate-risk research. But others' values are arguably relevant as well. The broader public, funding agencies, and even researchers themselves are all, in a broad sense, stakeholders to climate-risk research. Whether and how to transparently address values from these sources are important avenues for further research. Similarly, questions remain about how strategy assessments can best acknowledge ecosystems, future generations, or other interests represented at best imperfectly by present-day stakeholders.

We have presented ViMMs as a tool for incorporating values into research in a normative role. To situate this discussion with respect to related challenges in climate-risk research, we note that there is another, largely separate, role for values. Besides being *affected* by climate and management actions, people also *influence* coupled human and natural systems through their behavior (Yoon et al., 2022). Since behavior follows partly from values, accurately describing and modeling coupled systems dynamics may involve studying and modeling people's values (as well as other precursors to behavior). This is a *descriptive* role for values. Incorporating stakeholder values in this descriptive role is another important component of climate-risk research (NASEM, 2021b) but has not been our focus here.

The distinction between these normative and descriptive roles for values relates also to our definition of stakeholders as people *potentially affected by the climate impacts and strategies under assessment*. In addition to asking *who is affected*, a more common approach to stakeholder analysis adds a second factor to prioritization of whom to engage: *who has the most power or influence* over planning and implementation (Chevalier & Buckles, 2008; Moallemi et al., 2020; Reed et al., 2009) (Figure S1 in Supporting Information S1). Our position is that, from an empirical perspective, prioritizing stakeholders with power, influence, or agency is (almost by definition) a prudent approach for incorporating values in the *descriptive* role. For the *normative* role in outcome evaluation, however, our ethical position is that power and influence are irrelevant to characterization of who is a stakeholder.

The original incarnation of ViMMs (D. L. Bessette et al., 2017) (which we have modified and built upon here) grew out of an observation that participants in a planning process for managing coastal climate risks in New Orleans, Louisiana were not representative of the demographics of the city. While inclusive climate-risk assessments do not ensure inclusive decision processes, representation of stakeholder values within strategy assessments provides one pathway for affected people's values to enter policy deliberations. And while any study of stakeholder values is only as representative as the sampling strategy or engagement practices allow, the workflow illustrated here can provide one opportunity (through the focus groups or interviews; Figure 1) for participation with relatively low barriers to entry for stakeholders.

Data Availability Statement

This research did not use or generate any data or code.

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