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Effective stakeholder engagement in environmental problem-solving though group model building: An Oklahoma case study

Kristin L. Olofsson [a,*], Pavithra Priyadarshini Selvakumar [b], Kaitlin Peach [c], Maggie Leon-Corwin [c], Sam A. Stormer [c], Kuhika Gupta [c], Nina Carlson [c], Martha Sibley [b]

[a] Colorado State University, Department of Political Science, 1782 Campus Delivery, Fort Collins, CO 80523, United States [b] Oklahoma State University, United States [c] University of Oklahoma, United States

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ABSTRACT

Stakeholder engagement is a vital, yet under-accessed and under-studied, resource for tackling wicked environmental problems. This paper examines mental models – cognitive representations of "real" systems – refined through group model building (GMB) with stakeholders concerned with environmental issues in the US state of Oklahoma. During GMB, a diverse group of high-level decision makers met with a variety of physical and social scientists to collaborate on mental models concerning three environmental focus areas in Oklahoma: encroachment of eastern red cedar, grid and infrastructure resilience, and marginal water use and re-use. We ask: how do individuals from diverse stakeholder groups describe causes and consequences of key environmental problems in Oklahoma? Results from this analysis advance efforts toward developing socially sustainable solutions for environmental problems in Oklahoma and beyond.

Introduction

We, as a society, face innumerable policy issues, such as education, health care, climate, energy, environment, etc. Policy elites play a significant role in framing how these issues are understood as well as how we might develop solutions to these problems. We define policy elites as individuals involved in a policy issue with at least some influence on the policy outcome and/or specialized training or knowledge in the substantive issue. Importantly, policy elites often have a crucial role in shaping the direction of policy (Cobb et al., 1971) but typically have competing views about problems and solutions, anchored by differing values, assumptions, and interests. These differences tend to be even more pronounced in cases where we are confronted by "wicked problems" for which we do not have clear definitions of what the issues are or established rules about how to govern those issues (Agranoff and McGuire 2001; Head, 2019; Nohrstedt and Bodin 2020). The broad-ranging nature of wicked problems also requires "inclusive discussion, involving a wide range of stakeholders" in order to both define and resolve them (Head, 2019, 182). It is important to understand the underlying conceptualization of these wicked problems, which we recognize as mental models, as these in turn shape policy debates about how to solve wicked problems. Additionally, in contrast to more conventional policy problems, wicked problems require decision-makers and policy elites to think about cross-cutting domains and begin to formulate what they envision as the policy problem, causes, and solutions (Head, 2019).

Wicked environmental problems, such as eastern redcedar encroachment, infrastructure reliability, and water availability, serve as the basis for this research and the broader context of this paper, a project titled Socially Sustainable Solutions for Water, Carbon, and Infrastructure Resilience in Oklahoma (S^3OK). This project brings together scientists and stakeholders from a variety of fields to work toward better defining environmental wicked problems, their causes, and potential solutions in Oklahoma. While there has been extensive work exploring problem definition and opinion formation for the general public (Druckman et al., 2013; Druckman and McGrath 2019; Wildavsky, 1987), we know less about how policy elites from diverse backgrounds form their opinions when working together. Specifically in the context of this research, in which we understand policy elites to be not only individuals with influence on the policy process but also subject area stakeholders and scientific experts, it is imperative that we develop our knowledge about this diverse group of individuals. Tackling the complexity of wicked environmental problems demands wide expertise and authority. This research explores a specific approach – Group Model Building (GMB) – to not only identify problem perceptions among policy elites, but also uses cross-stakeholder engagement as a means by which to contribute to a shared problem vision and hopefully shared solution objectives. The goals of this

* Corresponding author.
E-mail address: Kristin.Olofsson@colostate.edu (K.L. Olofsson).

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research are two-fold: first, to capture an aggregate mental model of environmental problems in Oklahoma and second, to explore the utility of GMB as a means of encouraging diverse stakeholder engagement on critical environmental problems. The paper proceeds as follows: we first introduce the literature on stakeholder engagement among policy elites, followed by a discussion of GMB as a methodology for combining insights on policy problem definition by policy elites from diverse backgrounds. After introducing the methods, we present results with discussion and finally, a conclusion.

Literature review

Given that wicked problems are difficult to resolve, it is important for stakeholders to work toward a shared understanding and definition of a problem, which can then guide solution options (Head, 2019). Therefore, while empirical research can serve as a guide in our understanding of wicked problems, including environmental problems, the problem definition and proposed solutions are driven by the perspectives of those who have a seat at the table in defining them. This literature review first explores the role of policy elites in policymaking, through the lens of stakeholder engagement, then introduces group model building as both a theory and method for participatory policymaking.

Stakeholder engagement among policy elites

Given the complex and dynamic nature of environmental problems, stakeholder participation in environmental decision-making processes is crucial (Cwik et al., 2022; Haddaway et al., 2017; Reed, 2008; Stave, 2010; Winz et al., 2007). The benefits of involving stakeholders in environmental studies include capturing key environmental concerns (Ulibarri et al., 2019), accurately assessing sustainability (Watz, 2020), improving evidence base (Reed et al., 2008), and greater public acceptance and cooperation (Stave, 2002; Ridder and Pahl-Wostl, 2005). Overall, the policies and regulations developed from stakeholder participation are often more comprehensive, effective, and implementable (Beierle, 2002; Ulibarri et al., 2019).

Input from a diverse group of stakeholders allows for improved resolution of wicked problems by acknowledging diverse sets of values and worldviews (Davies et al., 2015). Much traditional schoalrship has considered policy elites to be only those individuals with direct influence on policy outcomes (Cobb and Elder 1971). We adopt a broader view of policy elites that recognizes traditional policy actors while expanding our conceptualization to include includes nontraditional policy actors – such as indigenous groups, nongovernmental organizations, and community groups – who either hold a vested interest in the outcomes or are experts in the subject matter. It is important to expand our understanding of policy elites to include these individuals so that we develop a broader view of problems and solutions. Values from policy elites from academia, public service, and the private sector, among others, are infused into the definition of wicked problems and consequently, the solutions. When policy elites are faced with wicked problems, they face both political and policy challenges, such as damage to their reputation, the potential of them taking up the majority of the agenda and time, as well as how responses to wicked problems can challenge ideological and governance goals (McConnell, 2018). These challenges may mean that policy elites are restricted in the way they define wicked problems.

The policy process literature indicates that policy elites use individual beliefs and expert information – which is not necessarily unbiased – to guide how they describe problems and formulate policy solutions (Sabatier, 1988; Funke et al., 2021; Weible, 2008). Using these beliefs, policy elites craft stories "that describe harms and difficulties, attribute them to actions of other individuals or organizations, and thereby claim the right to invoke government power to stop the harm" (Stone, 1989; 282). When defining problems, policy elites must define them in ways that make them fit feasible solutions, amenable to organizational action, and framed in a way that suggests there is an opportunity to improve the current situation (Dery, 1984; Turnbull and Hoppe, 2019). These narratives often develop within coalitions, resulting in coalition competition for problem definition. This means that there is often no negotiation between policy elites with competing perspectives to develop a more cohesive and nuanced problem definition.

When problem definitions are solely considered to be the result of competing coalition processes, we miss the ways in which actors from competing coalitions can come together to develop definitions that are more nuanced and can better capture the complexities and cross- boundary nature of wicked problems. We propose that mental models can provide a more nuanced understanding of how policy elites define and propose solutions to wicked problems. Every individual has a mental model that represents their cognitive understanding of the dynamic system they encounter (Hovmand, 2014). Development of shared mental models allows elites from diverse backgrounds who have competing policy beliefs and narratives about wicked problems to come together to formulate shared understandings of wicked problems that can still encapsulate the diversity of policy elite perspectives on problems. Consequently, problem definitions are not restricted by a single organization's perspectives and available resources. Furthermore, mental models encourage policy elites to think about the complexity of wicked problems, rather than allowing for them to be broken apart into isolated pieces. The construction of mental models can lead to improved problem definitions that allow for an increased number of solution options, as they become amenable to a wide array of organizations' actions and can be viewed as realistically able to solve with increased resources. However, it is important to acknowledge that mental models are still limited in their representations of the real world (Jones et al., 2011) and are inherently the product of socio-political forces and underlying power dynamics.

Group model building for stakeholder engagement

One way to develop mental models is through Group Model Building (GMB). GMB is a participatory approach designed to build the capacity of participants to think in a complex systems-informed way. Stakeholders actively participate in developing dynamic models (Andersen et al., 2007; Vennix, 1996). The direct involvement of the stakeholders in the modeling process is often linked to an increased understanding of the problem and the identification of implementable mitigation strategies (Hovelynck et al., 2010; Andersen et al., 2007). Vennix (1996) states, "group model building is a process in which team members exchange their perceptions of a problem and explore such questions as: what exactly is the problem we face? How did the problematic situation originate? What might be its underlying causes? How can the problem be effectively tackled?" (p.3). GMB is a resource and time-intensive process that requires participant buy-in and high-level engagement.

GMB aggregates diverse views of stakeholders from different functional areas on a particular problem, thus promoting transparency (Burgman et al., 2021) and legitimacy (Skål´en et al., 2018) in the decision-making process. Other advantages of stakeholder engagement in building a problem definition model are capacity development (Blokland et al., 2019), social learning (Choudhury et al., 2021; Fogel, 2005; Blackstock et al., 2007), social capital development (Stave, 2010), consensus establishment (D'Armengol et al. , 2021; Maani, 2002) and conflict resolution (Adamides and Karacapilidis, 2005; Davies et al., 2015). However, Hovmand (2014) claims that the instrumental role of stakeholder participation itself in GMB is often underestimated. Fogel (2005) addresses the lack of a common understanding of the need for stakeholder engagement in problem structuring. Hence, despite the significant benefits of involving the stakeholders in GMB, there is a paucity of literature available assessing stakeholder engagement in GMB to define and describe problems.

GMB was initially used to understand vulnerabilities in industrial processes (Greenberger et al., 1976) and in the private sector (Hovmand, 2014). Over the years, the growing complexity of problems across various fields and the corresponding need for systematic inquiries drawing on systems thinking resulted in tailoring this methodology to understand the behavior of complex systems across a wide range of disciplines and contexts (Vennix, 1999). Today, GMB is utilized in many research areas, including social sciences, engineering,

public health, cultural anthropology, policymaking, environmental systems, psychology, and medical and biological model building (Antunes et al., 2006). However, the extensive preparation, resources, time, and training required to utilize GMB hinders its widespread application (Hovmand, 2014). Zikargae et al. (2022) note that the involvement of diverse stakeholders in decision-making in various policy matters related to environmental protection is under-studied (2002), and every additional application bolsters the potential of the participatory approaches (Haddaway et al., 2017).

The complexity, uncertainty, and interconnectedness of the environmental challenges in the state of Oklahoma require a holistic understanding of the issue from scientific, social, and cultural dimensions. GMB comes into existence as a participatory method to address these complex environmental problems that require collective efforts and diverse perspectives of stakeholders. By encouraging public involvement, GMB serves as an effective interdisciplinary collaboration across diverse stakeholder groups—such as those from government, businesses, and communities—to better optimize policy and social decisions that improve the quality of the environment (Sexton et al., 2000). Hence, GMB was chosen as a method to closely match the purpose of this research, to examine mental models refined by stakeholders concerned with environmental issues in the US state of Oklahoma.

This study contributes to the literature on cross-stakeholder engagement, particularly within the field of GMB, by studying the importance of problem definition on complex environmental problems in a real-world setting. Most of the existing literature on stakeholder engagement focuses on involving the public in a controlled experimental setting rather than an applied setting (Scott et al., 2016). The case study presented here shifts the emphasis from unrealistic controlled experiments to real-world problems, thus allowing the audience to better understand how stakeholders are involved in the group and social processes of mitigating environmental challenges. The case of Oklahoma in particular serves as a critical application of GMB, given the state's strongly conservative political ideology and consequent reluctance to engage on liberal-identified issues such as environmental management. Bringing together a diverse set of stakeholders in this context was indeed challenging and only happened through a years-long process of network building and developing trust in the project itself. In addition, by integrating mental models with the concept of wicked environmental problems, this study provides insights into the factors that shape policy debates and decision-making processes related to environmental issues. **Methods**

Utilizing qualitative content analysis and iterative narrative coding on data collected during GMB, baseline mental models developed through previous stakeholder engagement were refined to capture causes, effects, and prospective solutions of three critical environmental issues in Oklahoma (see Cavana and Clifford, 2006 for a similar approach). We use a robust, qualitative dataset comprised of textual data as the foundation for this project based upon mental models revised during GMB, detailed scribe notes, and GMB annotations.

Setting and context

This study takes place within the context of a broader project–Socially Sustainable Solutions for Water, Carbon, and Infrastructure Resilience in Oklahoma (S^3OK). This project centers on advancing socially sustainable, science-informed solutions for complex challenges at the intersection of changing weather patterns, fluctuating water availability and quality, changing land cover and soil health, and aging infrastructure within the state of Oklahoma (EPSCoR 2023).

Through continuous informal discussions and inductive narrative analysis of meeting recordings from a previous project event, three wicked environmental problems in Oklahoma emerged that are the focus of GMB here. These include problems related to eastern Red Cedar Encroachment/Land Management, water treatment and re-use, and grid and infrastructure. Eastern red cedar encroachment across Oklahoma's great plains and agricultural regions greatly deteriorates soil quality, landscape, and poses a wildfire risk (Wang et al., 2018). Similarly, the diversity in scale of water systems and resources available to water systems managers pulls challenges associated with water treatment and re-use to the forefront for project stakeholders (Wineland et al., 2022; Schipanski et al., 2023). Finally, in the face of the severe weather that characterizes Oklahoma, challenges associated with aging and damaged grid and infrastructure inhibit Oklahoma's resilience to the changing climate (Shrestha et al., 2023).

In addition to collaborative problem definition of key environmental problems, the S^3OK project seeks to advance socially sustainable solutions to the challenges identified throughout the project. This requires the integration and respect of diverse belief systems and social narratives, and effectively engaging diverse stakeholders from the public, private, and non-profit sectors and a network of scientists who work in each of the wicked problems areas to provide a better understanding of problem causes, and to develop an initial solution set. *We use GMB to advance this initiative by refining the problem domain associated with each of the identified environmental challenges.*

GMB sessions occurred during an annual project meeting for S^3OK. This meeting enabled face-to-face engagement among project stakeholders: decision makers comprise the Opinion Leader Advisory Network (OLAN) and physical and social scientists comprise the Extended Peer Science Advisory Network (EPSAN). Each group played a valuable role in the project and had interact multiple times prior to GMB. OLAN members provide project guidance, facilitate cross- stakeholder understanding of wicked problems, and enhance engagement and collaboration. EPSAN members were primarily internal to the project and mostly comprised of S^3OK science team members. The recruitment of members to OLAN and EPSAN was initially led by a community leader with more than 30 years in Oklahoma policy and politics and has been augmented and maintained by the project's research practitioner who has extensive experience working in and with the public and nonprofit sectors. Membership of these networks was shaped to represent a diverse group of individuals from public, private, and nonprofit sectors, with a range of age, experience, and organizational resources. Research project leaders particularly identified the identification and recruitment of organizations that were historically under-represented in formal policymaking in Oklahoma, such as Native American tribes and rural communities. Representation of those groups and others was emphasized within both OLAN and EPSAN. GMB sessions occurred at the end of the second year of the project, during which OLAN and EPSAN members had already been engaged in several ways in the project: focus groups, annual conferences, monthly communications, online forums, research presentations, and one-on-one discussions, among others. *GMB process and methodology*

35 S^3OK OLAN members and 30 EPSAN members were split into three GMB sessions, each focusing on environmental problems in Oklahoma from which baseline mental models were generated during the first annual meeting: Red Cedar Encroachment/Land Management, Water Treatment and *Re*-Use, and Grid and Infrastructure.

GMB participants were each assigned to one of the three sessions based on their substantive area expertise and field of practice. Each session included one facilitator, two scribes, one mental model annotator, and 10–12 OLAN and EPSAN members as well 3–5 research team members (Table 1).

To ensure that stakeholders with differing values, assumptions, and interests were represented in each session, policy elites were spread into different sections based on expertise and organizational affiliation. OLAN members in the Red Cedar Encroachment/Land Management GMB session included private sector managers, ranchers, a private attorney, state agency leadership, and tribal nation leaders. The water treatment and *re*-use GMB session included OLAN members from tribal nation and county government leadership, state agencies, an environmental nonprofit director, private consultants, and a chamber of commerce representative. In the Grid and Infrastructure GMB session, OLAN members included a private attorney, a municipal planner, an electric cooperative engineering lead, nonprofit leaders, state agency leadership, an energy consultant, and a municipal utility director.

Facilitators reviewed scripts generated for each room that used the same basic template for the introduction of the GMB exercise, followed by a brief review of the baseline model developed from the previous year's annual meeting. Throughout the GMB, facilitators provided structure to the session and ensured a balance of insights were received from stakeholders in the room that came to the table with a variety of expertise and insights.

In the year prior to the GMB sessions, OLAN and EPSAN members had met online in focus groups to discuss: What are the most critical (environmental) problems for Oklahoma? Why are these problems critical, what is the cause, and who is affected? Sessions were recorded and transcribed, then used by the research team to create baseline mental models for the GMB sessions, following Cavana and Clifford (2006). Using inductive and iterative thematic coding approach, problem categories were identified for each theme as well as connections repeatedly emphasized throughout. Only those concepts that were emphasized repeatedly were included in the baseline models; we note that totality in the baseline model is neither required nor necessary as the goal of the GMB sessions is to spark discussion among participants. It was important, however, that the baseline models were derived from discussions among the same group of policy elites at prior meetings.

The session began with OLAN and EPSAN members annotating and adapting the baseline mental model independently, followed by facilitators soliciting iterative feedback on the model.[1] Simultaneously, annotators were updating the model while scribes were noting comments and concerns. The three GMB sessions ran simultaneously for one hour, and project researchers collected two archival forms of textual data for analysis of GMB results. This included detailed scribe notes, taken by a researcher throughout GMB discussion that detailed verbatim comments/suggestions made by participants, the frequency with which specific keywords and suggestions were made, and the general tenor and context of the conversation. Similarly, while GMB discussions were in progress, another project researcher made annotations to each baseline mental model–modifying connections on the baseline model, adding nodes and connections to denote topical considerations for each problem area, and re-arranging the model structure as appropriate. This produced the final model for each problem area, and produced valuable insight into the kinds of insight project stakeholders with diverse backgrounds provide. Full models produced during the GMB sessions were taken directly from the engagement process during the sessions and clarified when necessary using scribe notes before being assessed by lead researchers on the project.

Table 1

Theme	OLAN members (organization affiliation)	EPSAN members (organizational affiliation)
Red cedar encroachment/ land management	• Land managers • Private attorney • State elected representatives • Tribal nation representation	• University researchers
Water treatment and re-use	• Tribal nation representation • County government officials • State agency officials • Environmental nonprofit • Consultants • Local government officials	• University researchers
Grid and infrastructure	• Private attorney • Local government officials • Electric cooperative representation • Nonprofit leader • State agency officials • Consultants	• University researchers

GMB participants.

Results

Mental models produced during the GMB sessions reflect an aggregate perception of policy elites regarding wicked environmental problems in Oklahoma. The results illustrate the value of the group model- building process across diverse stakeholder groups. While these models are highly reflective of the discussion that occurred in those sessions, they are also an artifact of the participants and socio-political conditions. We do not suggest that these models are definitive, but rather instrumental as a tool in and of themselves to produce shared problem perceptions and deepen our understanding of these issues across policy elites with differing policy objectives in complex issue spaces. As demonstrated by the fact that the initial models were developed based on the first annual meeting, these models are also likely to evolve overtime, particularly as stakeholders continue to engage across industry and substantive areas.

Red Cedar Encroachment/Land Management

From the transcripts of previous year meeting, research team members constructed an initial mental model (see Fig. 1) that illustrates a baseline aggregate mental model of how eastern red cedar (ERC) encroachment impacts Oklahoma. Academy attendees noted the direct impact of ERC encroachment on carbon sequestration, water use, soil health, land management, and wildfires. Reciprocally, land management was noted to impact ERC encroachment, water use, and prescribed burning. The baseline model also illustrates the connection between wildfire, prescribed burning, and air quality. These identified factors are notated through boxes, and directional connections are notated through arrows connecting the boxes.

During the GMB exercise, the Red Cedar Encroachment/Land Management breakout group modified and expanded upon the model above. This new model (see Fig. 2) includes added features for consideration and refines how we understand the relationship between new and

[1] Each session was run by a trained facilitator with the same script (minimally varied based on theme). Facilitators were tasked with ensuring that each participant was given similar time to participate. This was an overarching goal of the meeting and research project. We acknowledge that even in cases of heavy facilitation, there is often a skew in power in discussions. The research team attempted to correct for this issue with extensive training in advance of the GMB sessions, as well as extensive pre-session communication with participants.

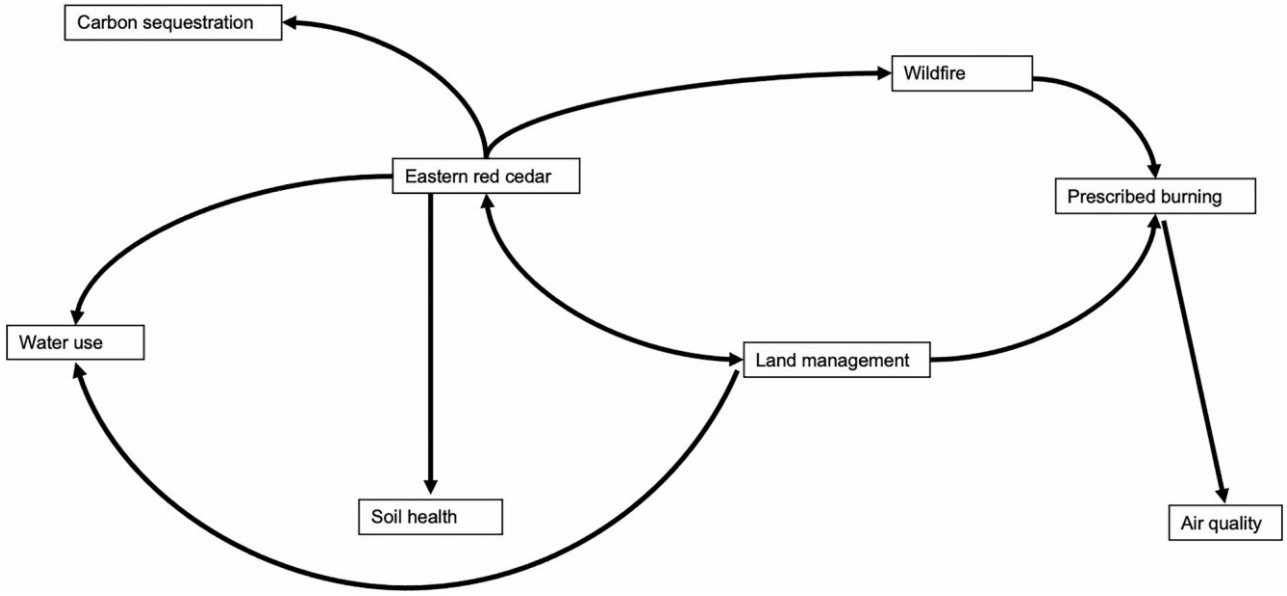

Fig. 1. Baseline mental model for Red Cedar Encroachment/Land Management.

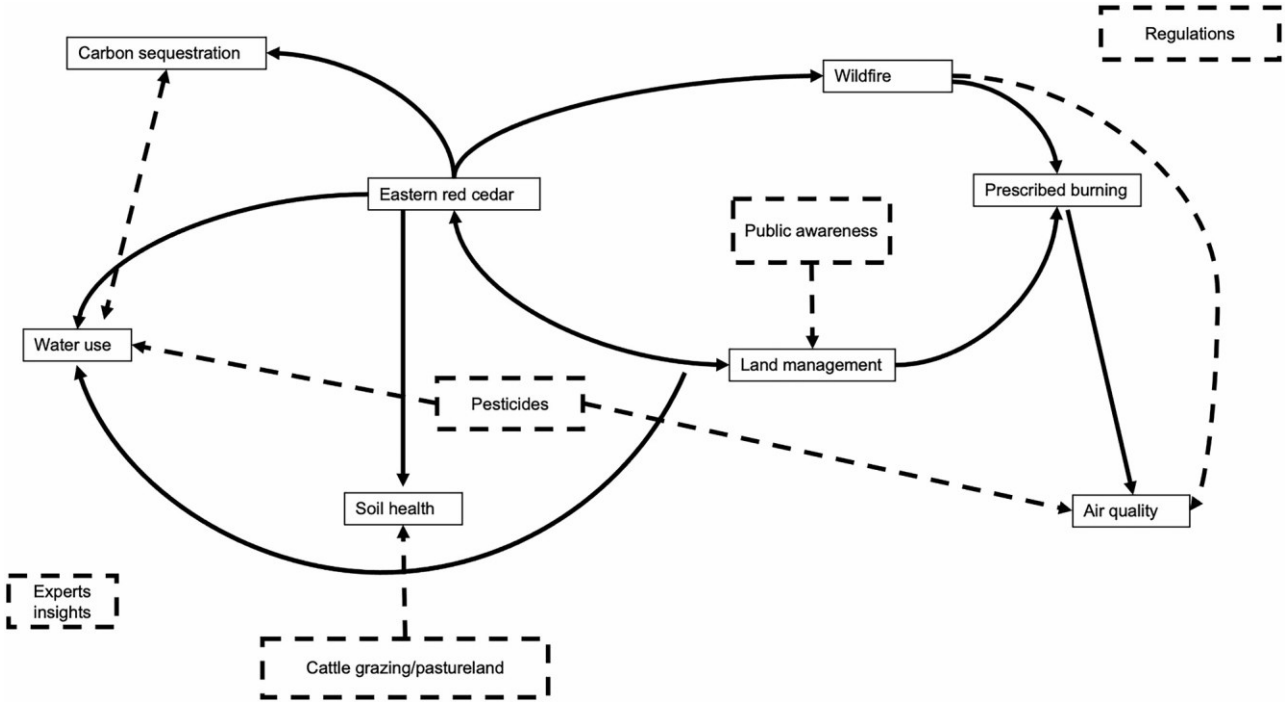

Fig. 2. Full mental model for Red Cedar Encroachment/Land Management.

established factors. These new features are represented on the updated model using a dashed and bolded outline.

New connections in the ERC full mental model reveal the complex and interrelated nature of how ERC shapes the environmental landscape in Oklahoma—such as the impacts of wildfire on air quality; cattle grazing pastureland on soil health; the reciprocal effects of water use on carbon sequestration; and public awareness on land management. In addition to better illustrating the full scope of challenges related to ERC, discussions during GMB gave new insights into the relative importance of related topics. Using the methodology described in the previous section, we were able to assess which issues were most salient in each discussion by quantifying the percent of discussion around each topic. For example, when discussing ERC encroachment and related issues, in addition to discussing ERC itself (15% of discussion), OLAN members particularly emphasized solutions and challenges related to land management (26% of discussion), with somewhat less discussion regarding soil health (11% of discussion) and water use (9% of discussion).

Water treatment and re-use

Many issues related to water treatment and re-use in Oklahoma were discussed during the GMB process. Fig. 3 illustrates the baseline mental model of the various interrelated factors that influence this thematic area. As with the initial ERC mental model, each of these factors are denoted with boxes, and directional connections are noted using arrows. For example, in the baseline model, participants noted delineation between the broad reach and

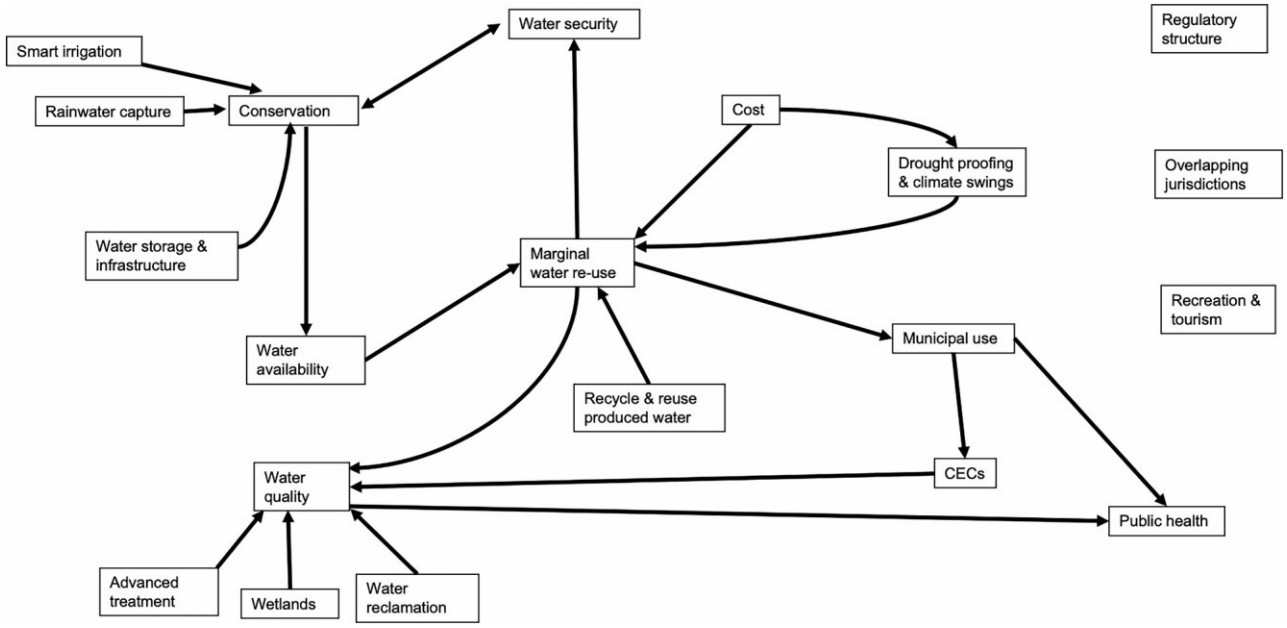

Fig. 3. Baseline mental model for water treatment and *re*-use.

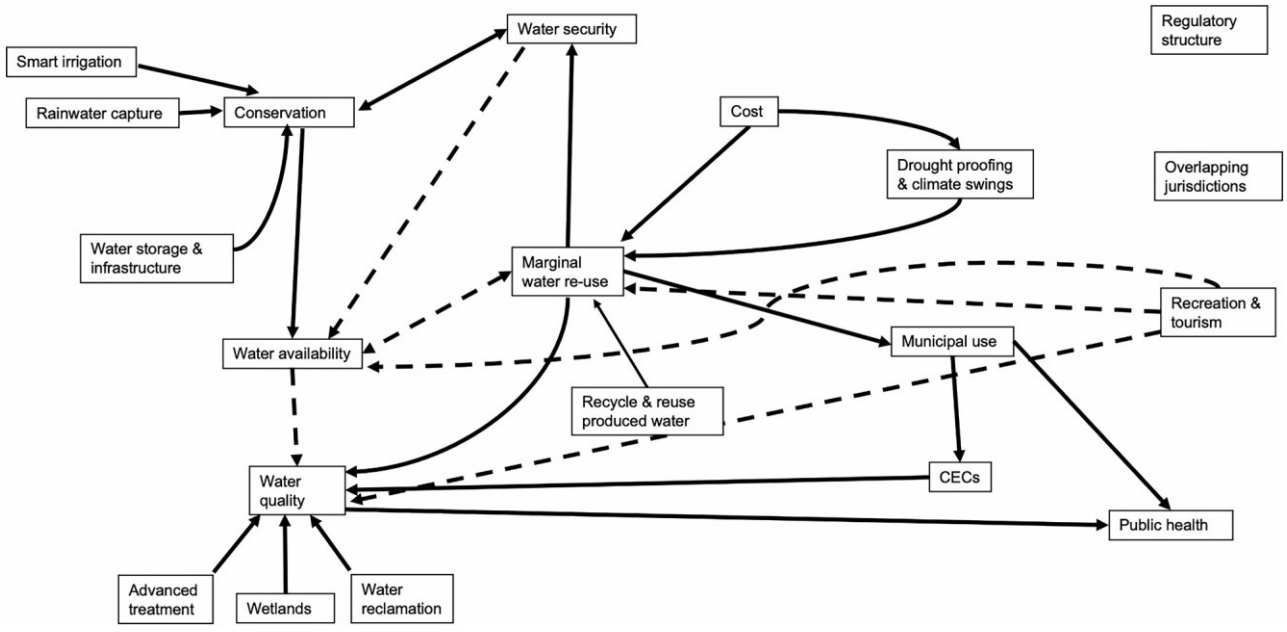

Fig. 4. Full mental model for water treatment and *re*-use after GMB.

interrelated nature of water-related environmental problems in Oklahoma. Factors such as cost, drought- proofing and climate swings, recycling and re-using produced water, and water availability were each noted to impact marginal water re-use. In turn, challenges associated with marginal water re-use directly impact water quality, use, and water security.

Conservation, central to the conversations for the baseline model, was noted to be meaningfully influenced by techniques such as smart irrigation, rainwater capture, and water storage & infrastructure. In turn, conservation was noted to shape water availability and water security. Water quality was recognized as having a direct influence on the public health of Oklahoma and was another central concern in the baseline model. Factors identified to influence water quality included contaminants of emerging concern (CECs), wetlands, and water management techniques (such as water reclamation and advanced treatment). Relatedly, municipal use of water—of central concern to OLAN members representing municipalities and communities across Oklahoma—is impacted by marginal water re-use, shapes public health, and is related to CECs. Each of these dynamics is in turn impacted by a regulatory structure that involves overlapping jurisdictions and competing interests—such as those posed by the recreation and tourism industry.

Fig. 4 shows the results of water treatment and *re*-use GMB exercise during the Academy with new connections and nodes. Here, the GMB process yielded several new connections between factors. Many of the GMB discussions refined the model as it concerns recreation and tourism, a significant economic driver in southeastern Oklahoma shaped, in part, by permitting. OLAN members discussed the recreation and tourism industry's impact on water quality, water availability, and the ability to recycle and reuse produced

water. Moreover, OLAN members noted the relationship between municipal water use–including industrial use and downstream flows– and marginal water re-use which, in turn, impacts water availability.

In addition to better illustrating the full scope of factors related to water treatment and re-use, discussions during GMB demonstrate the relative importance of related topics. When discussing water treatment and re-use more broadly, in addition to discussing water treatment (15% of discussion) and re-use (15% of discussion) generally, OLAN members emphasized topics related to water availability and water quality (31% of discussion), and to a lesser extent also discussed the influence of recreation and tourism on water availability (12% of discussion), and the ability to recycle and reuse produced water (12% of discussion).

Grid and infrastructure

Challenges concerning *Grid and Infrastructure*, and electric grid resilience more specifically, were among the forefront of discussion for the baseline models, particularly given the then-recent concerns surrounding the reliability of Oklahoma's electric grid infrastructure due to a 2021 ice storm. Fig. 5 illustrates the baseline model of factors that influence electric grid resilience.

The baseline model captured factors that influence electric grid resilience. For example, factors such as regulation, electricity mix, and extreme weather were each noted to directly impact electric grid resilience, which in turn, impacts public health. The Grid and Infrastructure GMB session yielded new connections between factors that better illustrate how various factors shape electric grid resilience in Oklahoma (see Fig. 6). In particular, OLAN members drew additional connections noting how extreme weather shapes the economy and transportation. GMB discussions also elucidated transportation's influence on public health, grid resilience, and climate change. Here, OLAN discussions also recognized that climate change affects the economy.

When discussing public health, GMB discussions generated new connections between public health and regulation and their reciprocal relationships with the economy. Here, OLAN members noted that each is major drivers of quality of life for Oklahomans. Reflecting the complex systems thinking OLAN and EPSAN members engaged in during GMB, an additional reciprocal relationship between the economy and transportation was identified. Finally, the GMB process generated new connections delineating the influence of regulation on transportation and electricity mix.

At the conclusion of the session, the resulting mental model provided significantly detailed insight into the critical and dynamic nature of grid infrastructure issues in Oklahoma. As with the other breakout sessions, project researchers were also able to quantify the emphasis of the discussion overall. In the grid and infrastructure conversation, participants emphasized solutions and challenges related to educating the public (14% of discussion), the importance of considering revenue (14% of discussion), and the way revenue can be harnessed to improve grid resilience (8.11% of discussion).

Discussion

We now consider in more detail some of the updates to the mental models for each of the focus areas: Red Cedar Encroachment/Land Management, water treatment and *re*-use, and grid and infrastructure. Furthermore, we will discuss how these models contribute to the broader project and our understanding of decision-making processes among a diverse group of stakeholders.

Red Cedar Encroachment/Land Management

Additions to the ERC mental model developed during GMB include cattle grazing pastureland, public awareness, pesticides, and expert insights – many of which were expanded upon in discussion during GMB. Regarding public awareness, OLAN members noted that financial constraints, along with absentee landowners exacerbate a generalized lack of public awareness concerning the impact of ERC on Oklahoma's landscape. OLAN members identified how these newly added factors impact previously identified elements in the model. Specifically, OLAN members suggested the S^{3}OK team consider the role of regulations and expert insights on ERC. Regarding the role of regulations on ERC encroachment, discussions during GMB indicate that the regulatory landscape (particularly concerning conservation) could drastically shape how ERC encroachment is addressed. Moreover, OLAN members noted that regulatory changes informed by expert insights could provide solutions for combatting ERC encroachment. To this end, OLAN members asserted that this approach would provide a better understanding of

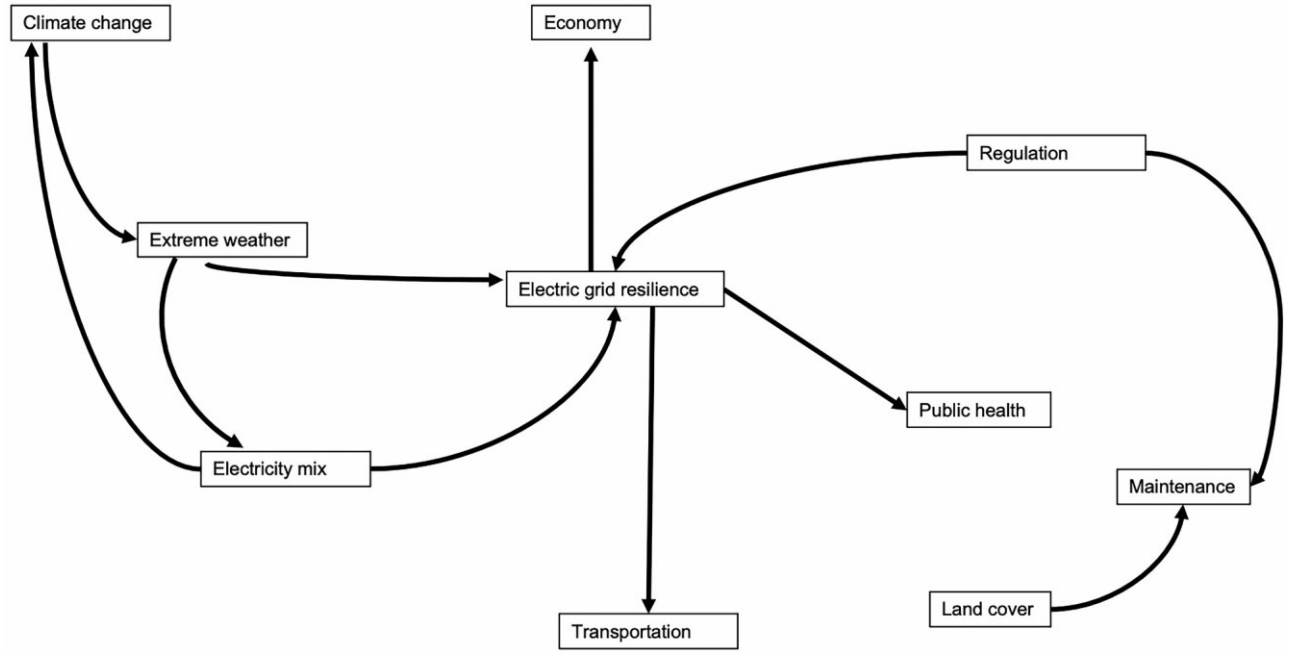

Fig. 5. Baseline mental model for grid and infrastructure.

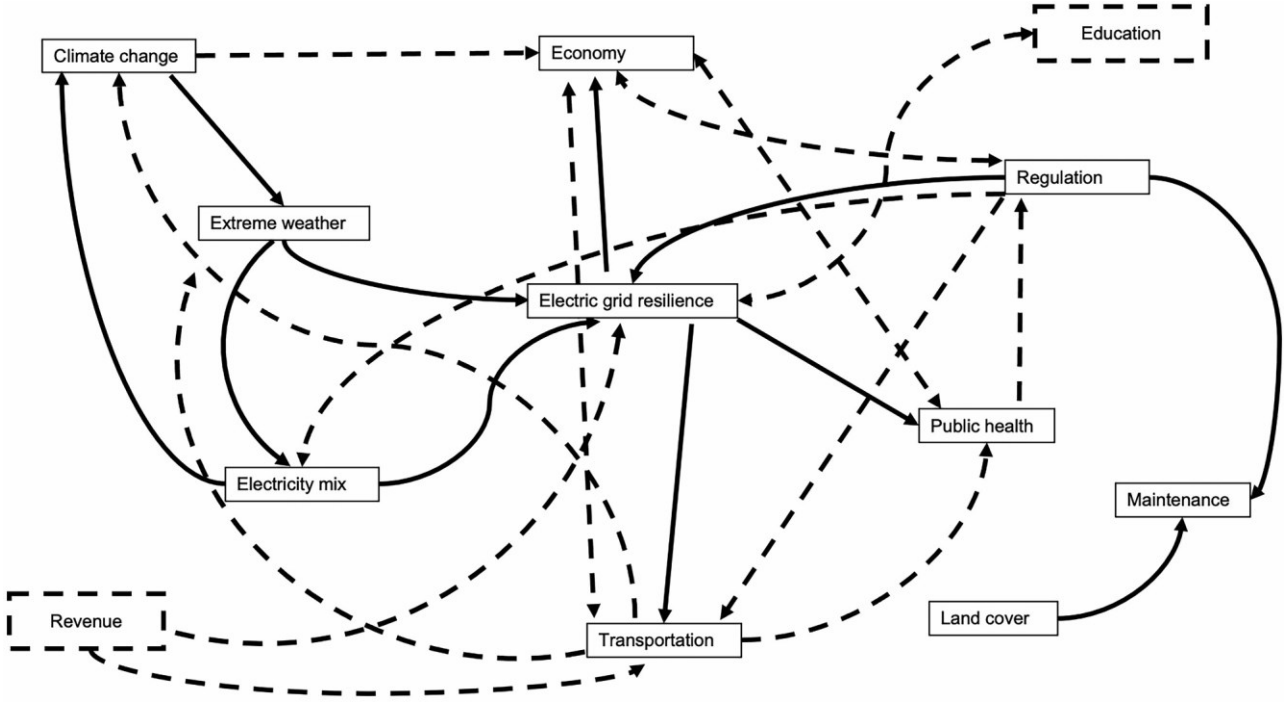

Fig. 6. Full mental model for grid and infrastructure after GMB.

possible solutions and mitigation strategies for ERC encroachment across the state.

Land management, in particular, emerged as a 'core issue' during GMB. To this end, OLAN members noted the complexities of land ownership and the nuances in intergenerational land management for non-native and tribal land owners in Oklahoma. Moreover, existing stakeholder engagement around land management is imbalanced and tribes need to be 'at the table' for discussions on land management–especially in light of tribal practices of land fractionation.

Water treatment and re-use

Marginal water reuse was discussed as particularly complex, especially in light of the desire to ensure equity in the process of reuse, educating the public, and enhancing Oklahoma's capacity to adapt. Additionally, OLAN members discussed the economic need to balance increasing rates and imposing costs alongside the general 'yuck' factor that permeates public perception of marginal water re-use. During GMB, OLAN members also detailed the relationship of water availability on water quality, and the impact of water security on water availability. Concerning the latter, water security concerns were particularly salient considering the cultural importance of water for Oklahoma's tribal nations and scarcity concerns induced by variations in precipitation and production along with limited cybersecurity for water systems.

Grid and infrastructure

To bolster grid resilience, OLAN members noted that proactive measures such as electric grid hardening, identifying a backup source for power in case of outages, and monitoring quality of electricity while improving current infrastructure were key. Baseline model discussions also emphasized that within this larger landscape, direct relationships exist between electricity mix and climate change; climate change and extreme weather; and extreme weather and electricity mix —illustrating again the complex and interrelated nature of the challenges and concerns surrounding electric grid resilience. No less relevant were OLAN and EPSAN acknowledgment of the influence electric grid resilience has in shaping the economy and transportation across the state and how land cover and regulation impact electric grid maintenance. Concerning regulation, OLAN members emphasized the existing regulations provided high level guidance without specific directions–impeding concerted efforts at fostering grid resilience and maintenance. To address this concern, OLAN members suggested looking to 'best practices' from other states or communities with similar grid resilience initiatives.

In addition to generating new connections between factors, GMB discussions resulted in two new factors being added to the mental model: education and revenue. OLAN members highlighted the importance of the reciprocal relationship between education and electric grid resilience. To this point, OLAN members specifically referenced education as important for transparency and improving public and private sector trust. OLAN members also indicated that having a public that is educated on issues related to grid and infrastructure allows people to respond early to issues that have an impact. Concerning revenue, OLAN members noted its impact on transportation and electric grid resilience, highlighting that generating revenue is particularly important to meet future energy demands as well as electric vehicle infrastructure.

Conclusion

Analysis of GMB with mental models representing Red Cedar Encroachment/Land Management, Water Treatment and *Re*-Use, and Grid and Infrastructure illustrates the myriad ways that diverse policy elites understand and define problem areas and prospective solutions with four themes emerging across the data. First, stakeholders emphasized the role of *regulations and regulatory structure* throughout each breakout group discussion. Second, stakeholders prioritized discussion of the need to *enhance public awareness* via education and engagement was emphasized throughout all three GMB discussions. Third, stakeholders emphasized the importance of *meaningful tribal involvement* in generating sustainable solutions across various topic areas. Finally, stakeholders emphasized the importance of *expert-industry-public collaborations* to address key problem areas in Oklahoma. By using an expanded conceptualization of policy elites in this study, we learn more about how diverse policy actors differently conceptualize wicked problems as well as how policy elites can be brought together for shared conceptualization to improve policy outcomes. Including a broader

group of stakeholders only improves the state of environmental problem solving.

There are a few key limitations to our study. First, while these models were developed collaboratively, they are only effective if stakeholders continue to work together and communicate while working on these problems. That means, GMB should be part of an iterative process, in which problems and causes can be re-evaluated and solutions can be added into the models. Future studies should examine GMB as an iterative process to examine how problems, causes, and solutions evolve as stakeholders collaborate more on issues. Second, though the stakeholder groups involved in the GMB process were diverse, each collaborator provided insight and feedback on models from an elite technical, science, and policy position. Thus, thematic trends and consensus that emerged from the data do not include insights and perspectives from the public at large. Though robust literature explores GMB with the general public, and our study contributes insights on GMB with policy elites, future studies should expand the scope of this activity to include both the public and policy elites. Finally, as is common with case studies, the generalizability of these findings is limited as insights deduced from this research are highly contextual and are tied largely to the locale and time in which data were collected.

Overall, the GMB process generated collaboratively designed mental models that better reflect the landscape of critical problems in Oklahoma. By shifting the focus from individual problem domains to a focus on the particular intersections between wicked problems, we can begin to focus on possible avenues that show the greatest potential to contribute to sustainable solutions. We see GMB as a method that not only yields an output of a mental model, but that the process itself can shape problem definition and perhaps even agenda setting in substantive domains to a stronger focus on solutions that have potential to address aspects of overlapping and intersecting problem areas.

Declaration of Competing Interest

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Data availability

The data that has been used is confidential.

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