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Review

No Stakeholder Is an Island: Human Barriers and Enablers in Participatory Environmental Modelling

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Abstract: Sustainability science strives to hone our ability to tackle problems that involve interconnected economic, social, and environmental systems. Addressing the root causes of these problems requires a more nuanced understanding of how human behaviour can undermine stakeholder engagement efforts towards effective conflict management and resolution. Participatory modelling—the co-production of knowledge via facilitated modelling workshops—plays a critical role in this endeavour by enabling participants to co-formulate problems and use modelling practices that aid in the description, solution, and decision-making actions of the group. While the difficulties of modelling with stakeholders are widely acknowledged, there is still a need to more concretely identify and categorize the barriers and opportunities that human behaviour presents to this type of engagement process. This review fills an important gap in participatory modelling practice by presenting five broad categories of barriers, along with strategies that can assist in overcoming them. We conclude with a series of actions and future research directions that the participatory modelling community as a whole can take to create more meaningful and behaviourally-attuned engagements that help stakeholders take concrete steps towards sustainability in natural resource management.

Keywords: social-ecological systems; participatory modelling; stakeholder engagement; human behaviour; social learning; behavioural science

Citation: Kenny, D.C.; Castilla-Rho, J. No Stakeholder Is an Island: Human Barriers and Enablers in Participatory Environmental Modelling. *Land* **2022**, *11*, 340. https://doi.org/10.3390/land11030340

Academic Editor: Andreas Neef

Received: 11 January 2022
Accepted: 21 February 2022
Published: 25 February 2022

1. Introduction: Tackling Wicked Problems of SES with Participatory Modelling

Addressing the social-ecological challenges of the Anthropocene requires a more nuanced understanding of the way humans perceive conflict and how people's knowledge, motivations and behaviours can get in the way of collaboration and the implementation of corrective actions in the face of complexity [1]. Complexity is a hallmark of social-ecological systems (SES)—characterized by uncertainty, nonlinear dynamics, the potential for regime shifts, self-organization, and a strong interdependence between ecological systems and the social systems that depend on them, driven by the interactions between resources, actors, and institutions at and across multiple scales [2,3].

Conflicts of values and interests of stakeholders seem to be a pervasive factor contributing to the 'wickedness' of SES issues [4]. This means human behaviour—as dominant force within SES—can be considered a *root cause* of undesirable trajectories or system states, but at the same time it is a central part of any solution [5]. A corollary is that, ultimately, one of the keys to improve the state and/or trajectory of SES is to transform human behaviour within it [6]. *Thus, how can this be achieved?* In order to improve the state or trajectory of SES, issues need to be 'owned' by the stakeholders of the system that we seek to change. That

sense of ownership helps to create a desire for change [7] and is a driving factor behind participatory approaches that are so widely advocated for.

Here, we argue that participatory approaches are only as good as our understanding of how people comprehend and assimilate knowledge about the systems they are part of. Participatory approaches ought to foster stakeholder learning of the kind that helps people transcend their own worldviews [8], sometimes referred to as transformative or loop learning [9–11]. Transformative learning can be thought of as a bottom–up approach—changing individuals to trigger change of the system as a whole. Working through problems of SES requires understanding how individual behaviours within the system both influence and are influenced by collaboration, group dynamics, social networks, institutions and policy [12]; feedbacks flow from the bottom–up and from the top–down. Participatory approaches prioritize this kind of bottom–up feedback, mediated through group learning. We, and other participatory modellers, conceptualize and aim for group learning that transforms stakeholders' worldviews or *mental models* [13,14]. A mental model is a "personal, internal representation of external reality that people use to interact with the world around them" based on an individual's experiences, perceptions, and understandings of the world [15]. One particular type of participatory process—so-called participatory modelling (PM), where scientists and stakeholders co-design a conceptual or empirical model of the system—has built a promising track record on building better a understanding and management of SES by providing a framework for engaging stakeholders, eliciting and shaping their mental models, and subsequently aligning them towards common goals [6,14,16–18].

However, we cannot expect the desired systemic outcomes to spontaneously arise after the implementation of these participatory practices. Individual learning is a necessary but not sufficient ingredient for systemic change. Learning must propagate through the system by transcending the individual to become situated and ingrained in the SES [6,19,20], sometimes referred to as social learning. Social learning plays a key role in this process, defined as changes beyond the understanding of an individual to critically deliberate, negotiate, and become situated within wider social rules, norms, power relations or communities of practice; this process occurs through social interactions between actors [6,10,21,22]. Crucially, social learning creates a shared understanding of the problem, defined as "stakeholders understand each other's positions well enough to have intelligent dialogue about the different interpretations of the problem, and to exercise collective intelligence about how to solve it" [23]. Arriving at this 'shared understanding', which can also be thought of as a collective 'mental model', is a key goal of participatory modelling. Given the critical role of human behaviour in determining outcomes for SES, participatory modelling (PM) is particularly well placed to promote learning at the individual level that can scale to a group level.

Participatory modelling (PM) occurs when stakeholders are engaged in a collaborative process of building a scientific model with researchers, as opposed to researchers seeking to simply 'extract' information from 'subjects' [24]. By comparing the outcomes of the model with what is observed in the real world, researchers engage in an iterative process of refining their hypotheses and the structure of the model until the 'artificial' world resembles the observed system being studied [25,26]. In the attempt to simulate or 'capture' reality, however, models can become incredibly complex and often require expert involvement in building, interpreting, validating, and maintaining such models. That is why involving stakeholders in the modelling process is an important consideration, as they can bring intimate experience and knowledge often unavailable to researchers and experts in creating these artificial laboratories [27]. PM, as opposed to traditional 'black box' modelling methods, seeks the collaborative co-creation of knowledge [28], and can be seen as a way to share information between researchers and stakeholders in an effort to build a shared understanding of a given system, its components, and its relationships. Some of the defining principles and goals of this kind of participation are to empower subjects to speak up and find their own answers, to integrate expert and local knowledge, and to involve the values, needs, and concerns of the community into the research process [29–31]. There

are many definitions of PM, but for this review, we define PM as: "a purposeful learning process for action that engages the implicit and explicit knowledge of stakeholders to create formalized and shared representations of reality" [17].

PM offers a systematic way to grapple with the complexity of SES issues by engaging stakeholders of a given problem to find a shared understanding and to implement collaborative solutions informed by science [32]. It is this 'shared understanding' that is so vital to the success of any PM effort, as a common understanding of definitions, the components, and relationships of a system, as well as empathy and appreciation for the perspectives of different stakeholders can create benefits long after the modelling exercise ends [33]. This is recognized in the literature, noting the positive effects when the "attitudes, beliefs, or preferences of the people managing or depending on resources are considered in the identification of problems and the development of solutions" [29,34] and it mirrors the desire for a shared understanding (not consensus) in problems of SES [35]. The more engaged stakeholders are, often the easier it is to reach that shared understanding [33] and achieve the intermediate outcomes of PM. Although there is some discrepancy over how to measure and evaluate these outcomes, some studies suggest that it is the intermediate outcomes (such as trust, communication, and the building of social networks) that seem to matter most, as they lead to the type of learning and behaviour change ultimately capable of changing the system [36–38].

The process of PM is often sought as the means to facilitate dialogue between stakeholders to achieve that shared understanding [33,39,40]. The model and the participatory process serve as the focal point for stakeholders and researchers to come together around a common purpose and to use the "modeling practices to define the descriptions, solutions, and decision-making actions of the group" [17]. The model thus becomes a 'boundary object', defined as a device that, if successfully implemented, can act as a bridge between various groups "to facilitate mutual understanding and cooperation" [26,36,41] by making people's perceptions and worldviews, i.e., mental models, explicit. These (often visual) objects help represent the connections between the people involved in the conversation, move us toward a more concrete representation of abstract concepts, and can be changed by proposals from any stakeholder [26]. As a boundary object, participatory models can empower and integrate many perspectives, encourage both individual and social learning, facilitate an exchange of worldviews and mental models between participants, and promote conflict resolution and collective decision making by becoming the object around which a socio-environmental issue can be 'mediated' [42–44] and those individual mental models can be transformed.

While the PM literature has discussed the difficulties of working with stakeholders, there is still a need to more effectively design for and to address the barriers that the nuances of human behaviour present to this kind of modelling process. A purposive literature search was used to identify relevant studies relating to participatory modelling, socio-ecological systems, and the presence (or absence) of a 'behavioural' lens or focus to the study, following a strategic and adaptive approach to the literature. We intentionally used the purposive review as this allowed, even encouraged, incorporating insights and findings from other fields to yield a synthesis that would prove difficult under a more defined, systematic approach. We sought to determine "To what extent do PM studies explicitly consider human behaviour as a driving factor in PM workshops focused on issues of SES? If so, how is that behaviour accounted for? What explanatory mechanisms or accommodations are systematically incorporated into the design and facilitation of PM as a result?" This review leads to the proposition that certain non-technical barriers or challenges are presented by working with people and their behavioural tendencies, which must be accounted for if enduring transformation of stakeholders and the system is an ultimate goal of any PM exercise. Publications were identified through the following databases: Science Direct; Scopus; Elsevier, using various combinations of keywords: "Participatory Model*"; "socio-ecological systems"; "behavior* science"; and "stakeholder*". The search was limited to peer-reviewed studies in English only. Results were screened using titles

and abstracts, followed by a skim of the full text to determine relevance and to check the reference list for relevant studies in a snowball approach that encouraged triangulating any insights from a synthesis of multiple sources. Our review lays the groundwork for designing and undertaking PM practices that empower stakeholders to make meaningful progress towards resilience and sustainability, and is useful for any looking to design or facilitate a PM process seeking to improve management of SES. Our findings and recommendations can be applied over a broad range of participatory research efforts in natural resource management.

The paper is structured as follows. Section 2 discusses the role of human behaviour within participatory modelling processes. Section 3 identifies and categorizes five human barriers in the context of participatory environmental modelling and outlines a series of recommendations on how PM processes may be facilitated to overcome each barrier. Section 4 concludes with a series of actions and future research directions that the participatory modelling community can take to facilitate more meaningful and behaviourally attuned engagements that help stakeholders take concrete steps towards effective collaboration in natural resource management.

2. Human Behaviour: The Achilles Heel of Participatory Modelling

Participatory models are a way of eliciting, involving, and learning from the perspectives of stakeholders, offering a way to extract individual and collective mental models and represent them explicitly [45]. In this role as a 'boundary object', the model provides a common platform and a common 'language' to understand the system of interest. PM allows stakeholders to engage with their own and each other's mental models, thereby "exposing personal knowledge gaps" [44] and aiding the development of an integrated understanding of complex social-ecological systems [45]. Shared understanding (not consensus), can thus be achieved, leading to enhanced communication and trust that endures long after the modelling process is over [36,40]. These and other 'intermediate' outcomes are among the most powerful benefits of the PM process.

Despite these benefits, there are a number of recognized shortcomings within the PM literature. Some of these are highly technical aspects, including model integration, model validation, and model sensitivity [46,47]. We are less concerned with these topics in this review. Instead, we focus on the use of the model as a boundary object and the 'intermediate' outcomes emerging from the social engagement and deliberation that occurs 'around' the modelling effort. Of the various outcomes that can be achieved by PM, intermediate outcomes (such as trust, communication, and the building of social networks) play a key role in mediating the learning and behaviour change necessary to ultimately improve the management of SES [36–38]. Furthermore, however, the PM community has historically paid less attention to 'how' this learning occurs [48–51], with unanswered questions concerning how the process can be deliberately and systematically structured to maximize those intermediate outcomes.

How can we empower SES stakeholders for systemic change? To do so, the literature suggests that our focus should be on understanding the role of human behaviour at the centre of a PM process. How, then, as facilitators, can we consistently, effectively, systematically, and consciously align with the patterns of human behaviour within a PM process? Here, the answers from within the PM community are less clear. Models support management decisions "beyond the time frame of a scientific research project" but often fail to account for human behaviour in making and executing those decisions [52]. Amazonas et al. [53] identified the need to incorporate social sciences "to better understand differences in perspectives and actions among project participants" and to incorporate cultural dynamics. Other authors have identified case studies that sought to "mitigate the BBHV (Beliefs, Biases, Heuristics, and Values) that commonly affect the judgement of all participants/experts, at both the individual and the group level", but failed to collect compelling evidence that PM led to any change in individual or collective reasoning [48].

PM experts have thus recognized the need to address individual learning, as also shown by some of the key questions they believe the field needs to address [17,42]:

- How can we measure learning, both of stakeholders and the wider community to which they belong?
- How can we identify, categorize, and address issues of communication through participatory modelling?
- How can the PM process actively understand, accommodate, and counter differing biases, beliefs, and values among stakeholders?
- What drives motivation and engagement in a PM process? What role does trust play and how can facilitators create conditions for its success?
- Furthermore, how do we ultimately scale participation in a PM process to ultimately impact the broader system and society at large?

All of these questions recognize the difficulty of meaningfully connecting with people as a part of PM to create an impact beyond the model that is collectively produced. Differing values and perspectives of stakeholders, particularly when dealing with socio-environmental issues, are often complicated and "deeply embedded in the minds, hearts, and practices of society" [54]. This is a barrier common to PM. For example, Squires and Renn note "that the interaction between modellers and stakeholders cannot be reduced to the communication of technical data and analytical results from modellers to stakeholders" [55]. Hare recognizes that learning may be more important than supporting decision making [56]. Furthermore, Luna-Reyes et al. identified 'cognitive boundaries' as a challenge, while pointing out "there is no agreed-upon process for bridging these boundaries" or clarity on what or how to communicate with stakeholders past these issues [26]. These and other studies revealed how human behaviour poses substantive challenges to the sort of transformational and systemic change sought by PM practitioners [32,49].

In the following section, we take on the question of 'how' to address individual and collective engagement, learning, decision-making, and collaboration while recognizing that the act of bringing people together does not guarantee success [57]. The interdisciplinary collaboration sought and often practised by PM is necessary but it is not sufficient to achieve the desired outcomes. While calls for participatory and PM efforts are growing increasingly popular, without an understanding of how we use and generate the social mechanisms needed for individual and collective learning, these efforts will continue to obtain mixed results [32]. To take PM processes to the next level, we need to integrate an understanding of the human barriers and design strategies to address them in the process, drawing from other fields of study that examine how people think, learn, and behave (see Figure 1). As stated by Bakken [58], "If participants' intuition about interrelationships and their consequences were correct, the need for outside-facilitated assistance would be limited to help surfacing issues and insights that had been hidden to the participants". In short, the complex and interdisciplinary nature of SES problems and modelling them with value-driven and biased stakeholders requires social fluency and accounting for human barriers, *as an active responsibility of PM practitioners*.

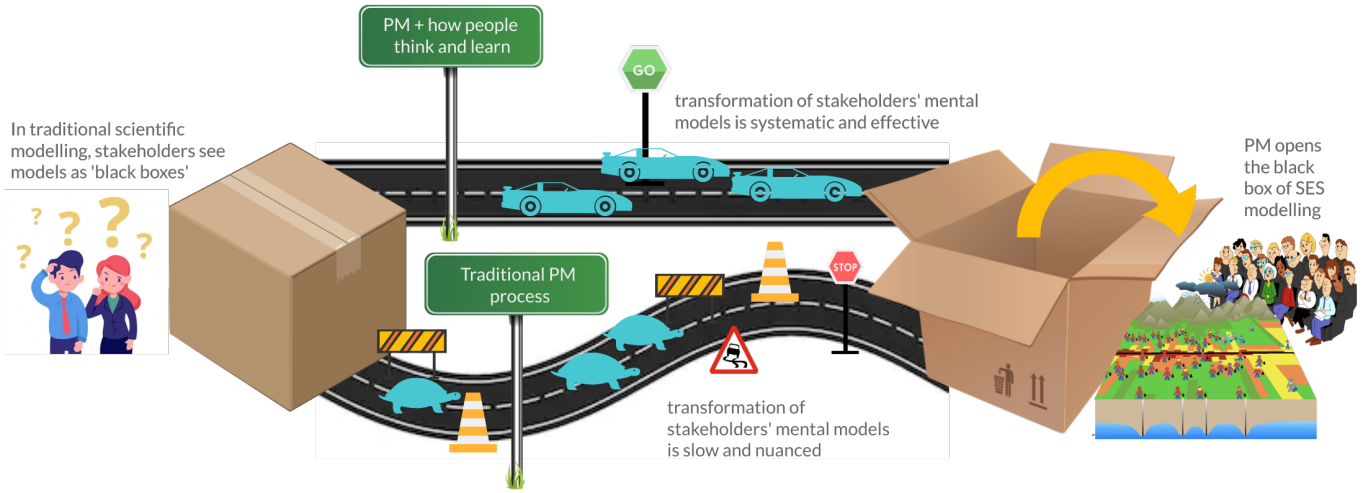

Figure 1. In PM, practitioners and stakeholders often face the challenge of 'coming together' to create an impact beyond the model being produced. By integrating an understanding of human barriers into the process, PM practitioners can design strategies to bypass those obstacles, drawing from other fields of study that examine how people think, learn, and behave. Modelling with value-driven and biased stakeholders requires a transdisciplinary and learning skill-set, as an active responsibility of PM practitioners in order to 'open' up the modelling process.

3. Human Barriers in Participatory Environmental Modelling

In this review, we divide human barriers relevant to participatory environmental modelling into five categories. These barriers, often hidden and unseen, can all be present to varying degrees in any PM exercise, and they can collectively or individually prevent stakeholders from coming together to achieve 'shared understanding' through the modelling process (see Figure 2):

- Subjectivity and biases;
- Managing conflict;
- Dealing with power;
- Communicating effectively;
- Being consistent.

To address each of the five identified barriers of PM, we will outline a series of recommendations on how PM processes may be facilitated based on principles, strategies, tactics, and insights from organizational learning, education, business, behavioural science, psychology, and other fields (see Table 1). Our recommendations highlight the role of promoting individual learning as a foundation to scale up participatory modelling towards the better management of SES.

3.1. Subjectivity and Biases

3.1.1. The Barrier

The first barrier is the inherent **subjectivity and biases of human decision-making**. While a simplification, scholars often describe humans as possessing two systems of thinking, one built on intuitive and quick decision making (System 1, S1), the other built on slow, conscious, ponderous, effortful thinking (System 2, S2) [59,60]. To avoid being overstimulated, our brains seek to be as efficient as possible, moving as much of our decision making as possible into System 1 to minimize our mental exertions [61]. However, this means we rely on mental shortcuts, called cognitive biases, which while efficient, can lead to less than ideal decision making. Work by behavioural researchers such as Kahneman and Tversky, Thaler, Ariely, Cialdini, and others revealed our irrational nature, and the implications it also holds for the way in which conduct science [62–66]. Their findings, while increasingly embraced by the scientific community, are still finding their place in the 'practice' of scientific inquiry, as it must change to acknowledge the inherent

subjectivity of our biases, beliefs, heuristics, and values (BBHVs). As stated by Glynn and others (2017), "Because our decisions and actions are often innately controlled, we need to better recognize, more explicitly incorporate, and sometimes counteract, S1 thinking. . . [as our] innate responses and actions are therefore often not appropriate or optimal for the longer-term, larger-scale benefit of a wider community" [61]. For PM, it is possible for that exercise to promote more S2 thinking, but that takes deliberate, informed consideration tailored to the stakeholders in the room [18,38]. It is simple in concept but much more difficult in implementation.

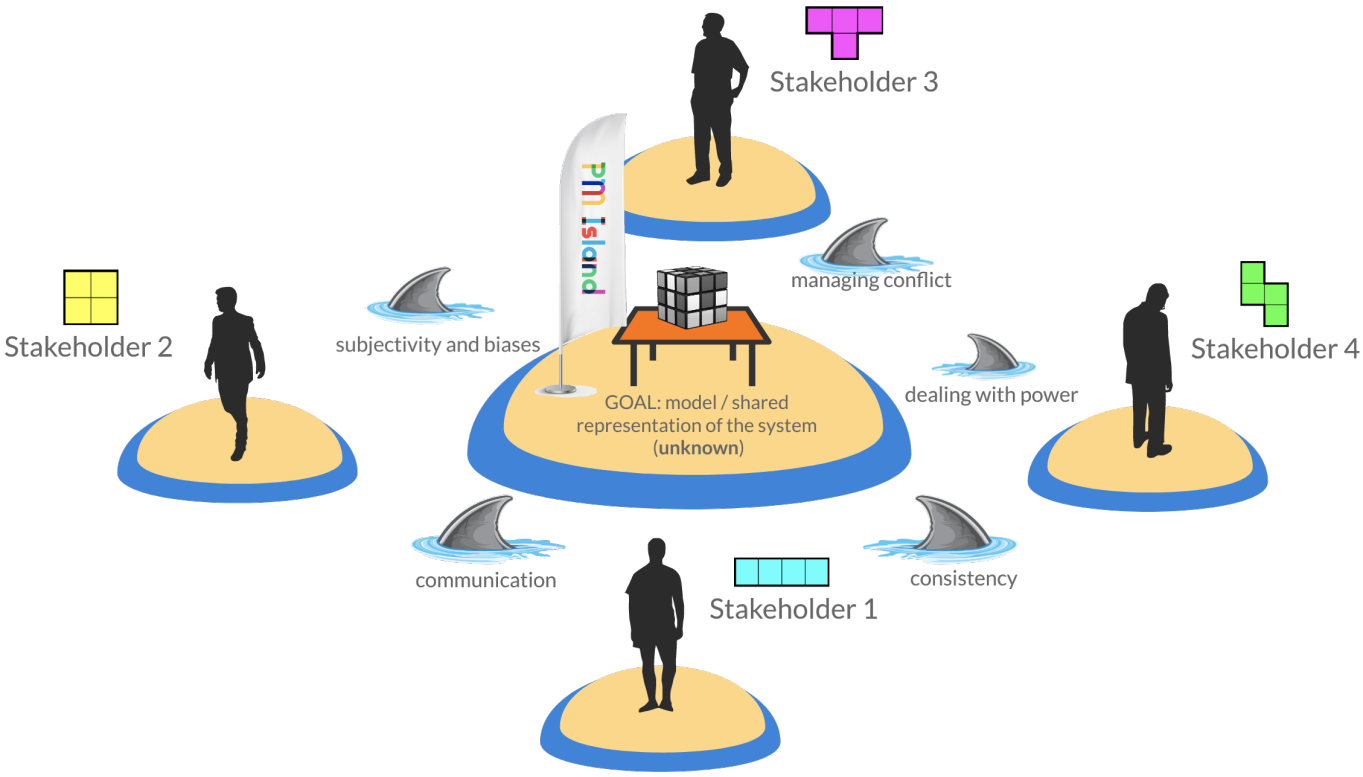

Figure 2. Often, cognitive and behavioural barriers can go undetected and limit, or even trump the success of any PM exercise which fails to account for how these factors might manifest in any given stakeholder workshop. We can group these human barriers into five categories: subjectivity and biases; managing conflict; dealing with power; communication; and consistency. Each of these barriers can show up to varying degrees in any PM exercise. Collectively or individually, they can prevent stakeholders from bringing their unique mental models together to achieve the ultimate goal of establishing a 'shared understanding' through the modelling process.

The issue of subjectivity applies to both stakeholders and to researchers, as both contribute to the modelling process based on their personal, biased, and subjective point of view. Such a 'distorted' perspective presents a risk that people contribute based on how they believe the world *should* function, as opposed to how it *actually functions in reality* [67]. In many ways, this is the exercise of PM: to bring this multitude of different mental models together, each flawed, in the hopes of creating a collaborative 'model' that better represents the reality of the system.

3.1.2. Some Solutions

All stakeholders, including experts and facilitators, bring with them an imperfect perception of reality, a documented challenge within the PM literature [42,61]. This presents a challenge as bringing people together also brings their differing and conflicting 'realities'. To address this, the first step is to adopt a strategy of building awareness. Awareness of the fact these cognitive barriers exist both for our stakeholders and for ourselves as

facilitators means that we can actively and deliberately design a process to counteract our flawed perceptions. Indeed, PM helps to instil this awareness by acknowledging that no one individual is likely to have a 'perfect' mental model of the world, but that group collaboration means we can get closer to a 'real' description of the system—a shared mental model. While people tend to shape their perceptions of reality to suit their purposes or perceived advantages, a product of 'confirmation bias', collective discussions in PM can (but do not guarantee) a more nuanced and balanced understanding. As organizers and facilitators, we should seek to actively avoid people hardening their views and becoming entrenched in their positions by creating awareness about the cognitive biases that everyone brings to the table.

The inevitable involvement of BBHV means that the different perspectives of individual stakeholders, including the facilitators, can distort both the PM process and its outcomes [28,29,61]. Within PM, this distortion has been recognized, and experts advise that PM practitioners clarify their assumptions about the system of study [38], consider their bias for certain methodological tools over others [42], and make clear who they have chosen to participate in the PM process and why [6]. However, more work can be done around understanding how underlying BBHV can help "explain why people think or act the way they do" and may dictate how to better manage the PM process to improve the management of SES [1,49]. For example, it may mean there needs to be a recognition of and possibly education around System 1 and System 2 thinking with stakeholders and facilitators, so that steps can be taken to promote more critical, reflective dialogue capable of creating the learning and sharing necessary for success [61]. This includes an appreciation of the differing values people bring to the table, and the awareness of how those values can shape the outcomes of the PM process [1,29,38,49,61,68,69].

Awareness can also be elicited by proper 'framing'. Framing refers to the way a problem is presented, as drawing attention to a certain aspect of a problem or issue dictates the way we perceive a problem, and therefore 'frames' the actions we might take to address it [70,71]; this is based on the focus of our attention assuming importance [72]. Put another way, when we focus on something, our mind assumes that thing is important. For example, the amount of news coverage an issue receives, such as on terrorism or climate change, is linked to the perceived significance of that issue among observers [73,74]. The more coverage terrorism receives in the media, the more important viewers believe that issue to be. As a result, PM practitioners should consider what is key information to focus on in a workshop, in that it will both direct stakeholder attention *and* suggest its importance.

We can take advantage of the in-built framing bias by beginning our PM process by drawing awareness to the presence of cognitive biases—informing stakeholders of what they are and what they look like. For example, confirmation bias means we look for evidence that supports our pre-existing beliefs and makes us likely to discount or ignore evidence or testimony that does not align with our views. Another bias made famous by Tversky and Kahneman is prospect theory, in which we fear a loss much more than we value any gain [62]; it hurts us more to lose, creating an underlying desire to avoid risk. (For a full list of cognitive biases, see [75]). For our own personal biases, some advice directly comes from the PM literature, where some modellers advocate that facilitators make their own mental maps before sitting down with stakeholders, to become aware of their own perceptions [76]. By acknowledging the presence of distorting cognitive biases, we make ourselves and our stakeholders more likely to watch out for them. Similarly, encouraging an atmosphere of mutual respect and 'keeping an open mind', perhaps in setting out the rules of engagement with stakeholders or 'principles of good practice' (as set out by Voinov et al. 2016 or van den Belt 2004) can also achieve a similar objective: framing the PM exercise as one in which we bring 'imperfect' individual mental models together, even those that do not agree with each other, in order to achieve a shared understanding [38,77].

3.2. Managing Conflict

3.2.1. The Barrier

The second barrier is the **inescapable and inevitable presence of conflict in group situations**. As a social process, PM exposes the values and beliefs deeply held in the hearts and minds of stakeholders [54]. Stakeholders cannot separate themselves from these values and, similar to politics, entering into discussions around the allocation of resources can be contentious and potentially disastrous for the viability and success of a PM process, and for the management of SES. Researchers must both know this conflict is inevitable [17] and prepare ways to constructively manage it. This preparation is vital so that at worst, conflict does not derail the process, and at best, it can lead to productive conversations and the sharing of differing perspectives.

As humans, we are hardwired to prefer clear divisions between 'us' and 'them' [78,79] and we typically cluster around those who we believe have similar values, attitudes, and beliefs. The drawbacks of this behaviour include groupthink, which can limit creativity [80], and conflict over deeply entrenched beliefs or values [81], often presented as a 'Simple Truth' [82]:

> *"A simple truth occurs when a "proponent of some view—let us call the view p—who endeavors to convince their audience to also adopt p on the basis of the claim that p is simply and obviously true. As it would be mad to reject a simple and obvious truth, the proponent uses their firm assertion that p is a simple truth as a winning argument for p... an appeal to the Simple Truth is a way of outing those who may see themselves as part of the group, but in fact are outliers. It thus sends a strong signal to those in the audience that they must accept p, or else be regarded as an outsider, or worse yet, a poser. This is why Simple Truth is often accompanied by a kind of brow-beating; the speaker affirms p as a Simple Truth, and then pauses to survey the audience for any signs of defection"* [82].

Furthermore, in any PM or participatory exercise, that stark dividing presentation of the 'simple truth' and the clear choice it implies is to be avoided. Presenting an issue as black and white both fails to recognize the complexity of the system, and tends to 'harden' people's views, potentially making conflict insurmountable.

Deeply held beliefs and values play a key role here in creating conflict [61]. Conflict is not limited to values, but they are often at the heart of many, as a stable, relatively unchanging part of all people. These differing values, if left unresolved, can then create problems for the PM process [83]. Some stakeholders may value profit, others may value protecting biodiversity, and other stakeholders may seek information for further research. For example, in the study by Borkowski and Hare (2007), they note the different objectives of researchers versus water managers, leading to the creation of models by researchers that did not meet the expectations of water managers, a result of different values and priorities. Water managers "have conflicting interests to balance. They have to manage a resource properly and in accordance with legal constraints and opportunities. They have to justify decisions to superiors and the public (and perhaps to a court of law)... Water managers, generally, have limited time to invest in models: either on being 'guided' on their use; being involved in their development; or reapplying tools developed in their own basin" [84]. In contrast, the researchers' primary interest is "to do research... Researchers need to produce scientific results on the focus of their work which might include lower scientific quality in areas which are not directly linked to the project's objectives" [84]. This has played out in numerous PM exercises, where one group values practical problems to solve, and the other values a deeper understanding of the issue [40,44,55,85,86]. Sometimes those different values can be overcome in a PM exercise. What is clear is that making a process participatory to bring those differing perspectives to the table is a necessary start, but more is needed as "simply improving communication between the two will not solve the problem alone" [84].

3.2.2. Some Solutions

Awareness and framing can help us acknowledge the 'flawed' perceptions of reality everyone brings to the PM process; framing can also assist with our conflicting 'values'. Conflict created by opposing values is a recognized problem within PM, and to navigate those values, people must find agreement on the value(s) of priority and then negotiate or compromise on the practicality of enacting that value [69]. Some of this may arise from negotiating the shared problem or purpose of PM, ideally at the outset of the process and occurring with stakeholders [32]. However, additional steps can be taken in the way conflicts and arguments are presented, and the selection of guiding values, such as 'seeking the truth' or collaboration. Drawing from political science, instead of presenting conflict as a zero-sum game, a facilitator should present an argument and the PM process, as a way of moving closer to the truth, particularly in light of everyone's 'flawed' perceptions [82]. Introduce the process as a way to reason together, and, despite disagreement, seek to see opposing viewpoints as reasonable and valid [82]. In practice, this might involve a brief session on the outset on logical fallacies or what a good argument looks like; philosophy has long discussed the essential criteria for productive argument, including a well-formed structure, relevant premises that work together to support the conclusion, and a reasoned rebuttal of critiques [87].

Disagreement arising from different values is actually a valuable part of the process, as those tensions are needed to enhance shared mental models rather than entrench people in their own static views [88,89]. There is a needed balance between conflict and collaboration but the atmosphere must be one of 'healthy argumentation' [82]. Establishing a shared value of collaboration at the outset can help with that, so that stakeholders during the PM process, even in conflict, can view one another as "striving to find the truth, respond to evidence, and track the best reasons", which makes it difficult to write people off as 'other' [78,82]. Fortunately, PM offers a way to bring people together to jointly and collaboratively produce information, in the form of a scientific model, as a proven way to negotiate values and differing stances [57].

While many of the papers written about PM fail to evaluate or suggest how the conflict of opposing or incompatible values might be navigated in practice, Morisette et al. (2017) laid out several useful practices including the "definition of a shared problem space, "what if" thinking, reconciling evidence, and developing common mental models". Particularly useful in creating a healthy argumentative space, Morisette and others (2017) discussed "psychological safety" in the context of PM, originally a term and concept from organizational learning and psychology [90]. Psychological safety describes the "perceptions of the consequences of taking interpersonal risks in a particular context", such as a workplace or a PM exercise; if present, psychological safety "facilitates the willing contribution of ideas and actions to a shared enterprise" such as sharing ideas, coming up with suggestions, or taking creative initiative [91]. Psychological safety recognizes that conflict in a shared space is unavoidable. However, if learning and innovation are paramount, people must feel secure in sharing their views and take interpersonal risks without judgment [91]. Daniel Kahneman, Nobel Prize winner and one of the visionaries of behavioural economics, used to famously ask their classrooms to not point out the errors of their peers' arguments. Instead of asking themselves, 'is that true?', he posed a different question: "What might that be true of?" [92]. That question and that perspective encourages curiosity and empathy. Furthermore, it builds the trust needed for people in the room to be vulnerable and share their perspective, thereby building psychological safety and enriching the process.

Trust is paramount to the process. Some trust can come from the transparency of the modelling tool, and the ease with which stakeholders can learn and use it [93]. However, building trust also involves listening, showing concern for opposing positions and perspectives, emotional vulnerability, and respect [89]. Furthermore, it is the job of those leading the PM process to facilitate that process. The facilitator can accomplish that through active listening, a strategy employed by both counselling and negotiators to ensure people feel

heard [94,95]. Active listening includes skills that can be picked up and practised quite quickly, although they take practice and time to master: mirroring involves repeating the last few words of someone else's statement, to show attentiveness and elicit further explanation; paraphrasing involves restating in one's own words, to try and take their perspective, which is sometimes combined with emotional labelling (e.g., "it sounds like you are frustrated" or "it seems like you feel powerless"); together, these and other skills can lessen the emotionality of an atmosphere and reduce the 'heat' of a conflict by naming the emotions at play, and demonstrate a genuine intent to understand other perspectives [95].

Role play is another tactic available to us, as this helps stakeholders to develop empathy for positions different to their own. The ability to consider a perspective that we have not lived is a defining human characteristic, and anthropologists have theorized that this provides an evolutionary advantage as our ancestors were able to learn from the experience of others (seeing a lion) without necessarily having to endure the danger (being eaten). Encouraging stakeholders, particularly those in conflict, to take up and defend the opposing position can help them appreciate why someone might hold that view.

This has been used in business and counselling settings and mirrors Rapaport's Rules (a social psychologist and game theorist) for good debate and argument:

- "You should attempt to re-express your target's position so clearly, vividly, and fairly that your target says, "Thanks, I wish I'd thought of putting it that way";
- You should list any points of agreement (especially if they are not matters of general or widespread agreement);
- You should mention anything you have learned from your target;
- Only then are you permitted to say so much as a word of rebuttal or criticism" [96].

Managing the subjective nature of humanity requires the skilful and deliberate management of conflict, as we seek to prevent people becoming hardened in their views, staunchly defending their positions with little room to budge. Thus, the tools offered to navigate conflict first involve awareness of those biases and the presence of conflict, but present them as opportunities for learning. One of the things we can do is to build empathy in our individuals for alternative or even opposing positions by creating an atmosphere of safety and trust and engaging in active listening throughout the process. It can also include additional strategies such as role play, where we are forced to take the position of an adversary and ponder why they might hold that position [57], however, at its core, managing conflict is first understanding that it is not inherently bad, and in fact is an important part of the learning process [97]. Furthermore, second, we can move towards the 'shared understanding' so key to the success of PM by creating an atmosphere in which people can share their perspectives without judgment and learn to understand and appreciate the views of others.

3.3. Dealing with Power

3.3.1. The Barrier

Conflict is also entrenched with our third barrier: **debates about power**. Stakeholders not only bring with them their values, culture, and social norms, but also their existing social hierarchies and power structures [17,29,33,40,98]. Unbalanced and unchecked power relations—or power asymmetries—in the PM process means powerful stakeholders could hijack the model or the process to serve their interests [29]. Not including powerful stakeholders means the process could lack credibility. Excluding disadvantaged groups would only further entrench existing power dynamics [33]. As such, efforts should be put into deciding who is involved in the process, and by extension, who is not included, as the power and institutional context in which PM occurs may very well determine the ultimate success or failure of the effort [93].

3.3.2. Some Solutions

Power and hierarchy may be difficult to manage within a PM exercise. It is possible that the history, culture, and conflict of a region is simply too great to overcome with a

participatory model, despite all of the best planning. Some of this can be addressed by who we invite to the exercise, a balancing act between involving key voices capable of advocating for and enacting change versus not letting certain interests overtake and manipulate the process for personal gain. Unbalanced and unchecked power relations in the PM process means powerful stakeholders could hijack the model to serve their interests [29]. At the same time, the absence of powerful stakeholders from the process means any efforts would lack credibility and legitimacy among the participants while the exclusion of disadvantaged groups would only further entrench existing power dynamics [33]. The PM process cannot escape the constraints of the "social contexts in which individuals are embedded" [6,99,100]. As such, extensive work should be put into deciding who is involved in the process, and by extension, who is not included, as the power and institutional context in which PM occurs may very well determine the ultimate success or failure of the effort.

The importance of stakeholder selection has been written about in the PM community [42,70,101,102]. A number of PM processes have implemented social network mapping/analysis at the outset of the process to ensure proactive and deliberate stakeholder selection and to account for power dynamics and social hierarchies [103,104]. Social network analysis maps relationships between stakeholders (individuals or organizations) to identify who may be the most powerful, who may be marginalized, or where groups have formed with regard to the issue at stake [42,100,103,105]. This can be achieved among experts before beginning the PM process, or with stakeholders as another form of a participatory model and to identify important links and actors in the social sphere for the issue at stake [42,106]. For a full discussion of stakeholder selection and other tools available (such as focus groups), see [107].

Another tool to assist in considerations of power and hierarchy are critical questions seeking to bring to the awareness of experts and/or stakeholders the assumptions and relationships they bring with them into the PM process. Ullrich and Reynolds (2011), from critical systems heuristics, and Mingers (2000), looking at soft systems methodology and questions from operational research, have both devised questions to assist with this task [108,109]. These questions include:

- Do my experience and skill suggest certain methods? Are those methods best suited for this situation? Have other methods been considered?
- What is my personality or cognitive style comfortable with?
- What is the history here? What methods have worked or not worked?
- What and who am I committed to in this situation?
- What resources do I have at my disposal?
- Do I need to learn more before entering this situation?
- What is the purpose of the system? What should be the purpose?
- Who benefits from the system right now? Who should benefit?
- What is the measure of success in the system right now? What should it be?
- Who controls the success of the system? Should that change?
- Where is there space for stakeholders to reconcile different perspectives on the system and situation at hand?

These critical questions [108,109] make us aware of our own pre-existing views and assumptions before beginning a PM exercise, and can also be used in questioning stakeholders to help them reconsider their own environment and hierarchies.

While much of this barrier of power may be beyond our control [93], we can still take an active role in the design of the PM process to mitigate, or at least reduce, the influence of power and hierarchy. As mentioned, the first step is making careful decisions around who is involved in the process. The second is coming to an agreed upon purpose with the invited stakeholders, achieving consensus on the 'why' of the PM exercise. During the actual exercise, group guidelines concerning how the process will be managed ought to be created, agreeing upon rules in the beginning about who will speak, for how long, and what the values guiding the process might be. A key concept for addressing power (including that of the facilitators over the process) is the transparency of the process. Being clear about

what decisions are being made and why so that everyone shares in that knowledge and can protest it if they like. As facilitators of PM, awareness of this power dynamic and the power concentrated in the facilitator's hand can play a key role in the success or failure of the group. Deciding who can participate, how people can participate, and what will be done with the outcomes can all lie within the facilitator's discretion. While there is no one-size-fits-all, being clear about what those decisions are, why they were made that way, and how those decisions align with the ultimate goal of the PM exercise can all be helpful taking a more active role in productively managing power.

This also means leaving a space for reasonable protest. Not everyone can agree, so creating a strategy for managing conflict also stands to benefit the process by giving any opposition a voice, increasing the legitimacy of the process, and potentially preventing the distortion created by groupthink. The military developed a strategy to assist with this effort, called 'Red Team'. Software developers and cybersecurity have also adopted it [110]. Creating a 'Red Team' means appointing a person or a team whose job may include "challenging facts and explicit assumptions, looking for implicit (unstated) assumptions, identifying cultural assumptions and developing targeted cultural questions for subject matter experts, challenging the problem frame (and proposing alternative frames), identifying cognitive biases and symptoms of underlying groupthink" and others [111]. By giving select stakeholders a role to seek out flawed arguments, particularly in the light of promoting an atmosphere of 'healthy conflict', we can bring awareness to the distortions in our thinking patterns, and find a way to constructively and collaboratively challenge power, whether that is of the group or an individual [112].

While the issue of power dynamics is always present in any participatory or social setting, caution needs to be exercised particularly when dealing with marginalized groups and interests [106]. Considering who stands to gain and who stands to lose (and some may be more sensitive to or damaged by losses than others) is good practice. Aside from the consideration and transparency that must be adopted as a part of the process, another tactic may be to have members of the marginalized group meet separately beforehand to discuss their interests and opinions, allowing them to build confidence in their communication and to identify potential shortfalls before proceeding to a larger PM workshop [70,113]. However, merely bringing marginalized stakeholders together is not enough, on its own, to overcome deeply entrenched power dynamics. If deliberate action is not taken to account for those social hierarchies, and to empower viewpoints and insights from these marginalized groups across major power and conflict structures, learning and transformation can stagnate [6,10,22,114]. For addressing power in particular, tactics and strategies such as those listed here can help, but a more holistic (and patient) approach is required for systemic and enduring change in the system of interest.

3.4. Communicating Effectively

3.4.1. The Barrier

Given the barriers above—subjectivity and biases, conflict, and power—how can PM practitioners address them with stakeholders? How can communication, before, during, and after the PM exercise help create 'shared understanding' and encourage action to be taken?

PM practitioners are not necessarily trained in the skills of effective communication, particularly in facilitation and managing a room of stakeholders (that are often in conflict). In PM, the relationships with and between stakeholders matter a great deal [28]. Effectively navigating these relationships includes practising communication skills such as metacognition, transparency, and conflict management. The degree to which communication directed by the practitioner can successfully manage and improve these social relationships determines a great deal of efficiency and success in the PM process [17,28].

While conflict is inevitable, navigating conflict during PM requires skilled facilitation which is not a guarantee for all PM practitioners [52]. Experts can often assume that subject knowledge in the system of interest is sufficient to guarantee a smooth, productive process

(*it is not*). PM practitioners can also be completely unaware of how their own cognitive blind spots and biases can contribute to communication difficulties: polarizing debate, promoting existing power hierarchies, seeking evidence to confirm pre-existing beliefs, and others [61]. Through bias, or through a lack of skill, if practitioners are not careful, we can skew the PM process before it even begins, carrying our own distortions in what we say and what we do as we interact with others in the PM room.

3.4.2. Some Solutions

In many ways, all of the strategies we discussed are strategies of communication, but two particularly powerful ideas are dialogue and reflection. By dialogue, we draw from learning theory to mean "a sustained collective inquiry into the processes, assumptions, and certainties that compose everyday experiences" [115]. This is a deeper conversation between stakeholders, and it is essential. The spirit we seek is that of the college seminar, where all are free to exchange ideas, constructively challenge, and encourage creativity in a collegial spirit for the purpose of improving the group's ideas [9]. It is not adversarial. The job of the facilitator is to create a space where this dialogue can happen, where views can be shared without fear of judgment or reprisal. Perhaps easier said than done, but if this is the spirit in which PM is engaged, benefits will follow.

An attitude of humility is key here. Despite the democratic spirit underlying participatory modelling, it is sometimes difficult, as experts or leaders, to remove ourselves from the certainty of our expertise. As facilitators, we should avoid assuming we have all the answers as 'experts', as one of the main reasons to engage in PM is to learn from the lived experience and intimate knowledge of stakeholders and to engage them in a collaborative process. While we may have scholarly knowledge, information alone will not unlock better behaviours. Believing that our stakeholders or ourselves are of the rational genus, homo economicus, has been shown time and time again to be a myth, in keeping with our first barrier [116]. Deeper work is required, and communication is crucial to unlocking those deeper levels.

The ability to question the positions of others and have your own viewpoint questioned can generate learning [88,89]. Furthermore, it is indeed dialogue, and the respect it implies, that can be used to resolve conflicts brought up in the 'encounter' and support the collegial learning atmosphere through social interactions in the pursuit of shared meaning [10]. Dialogue builds on the concepts we discussed: trust, empathy, psychological safety. It is not based on "winning arguments; it centrally involves finding agreement, welcoming difference, "trying on" other points of view, identifying the common in the contradictory, tolerating the anxiety implicit in paradox, searching for synthesis, and reframing" [9]. With dialogue as the focus, a PM exercise becomes less about filling people with information, as this has been shown not to drive behaviour change [116,117]. Instead, dialogue can be used to encourage the sharing, learning, and teaching of metacognitive skills such as critical thinking [118].

Similar to an attitude of humility, stakeholders (and this includes the practitioners directing the exercise) who learn **metacognitive** skills, to think about their own thinking and question their own assumptions are better prepared to face the complexity and uncertainty posed by the management of SES, and the modelling aspect of PM can reveal flaws in their assumptions or worldview. Ways to promote metacognition, specifically critical thinking, include but are not limited to an introduction to the concepts of double and triple loop learning [11,119,120], the questions asked by the facilitator (ex; Could you elaborate on that? Could you give an example? Do we need to look at this in other ways? (for a full list of questions, see Paul and Elder [121])), the promotion of tactics such as Rapaport's rules and active listening [94–96], and the practice of reflection as a key exercise during and after the PM process.

Reflection means we are encouraging people to evaluate their own beliefs and assumptions, and giving them the space to do so. To internalize the learning, stakeholders, including PM practitioners, should be given space to consider what might have changed

about their mental models, or where their worldviews might need updating [122]. Some of this is built into the PM process. The modelling process and interactions with other stakeholders and the facilitator provides feedback on an individual's mental model, reflection is key to then "diagnosing what matters, designing what could be, doing what we can and then developing a deeper understanding from reflecting on and evaluating that practical experience" [10]. Reflection builds on the awareness of assumptions we create, but it is a vital step towards the end of the process for people to consider how their worldview fits or does not fit with what has been explored by the group, and perhaps with what has been captured by the built model [89]. The built model and or computer simulation provides explicit feedback on the suitability of someone's mental model, and providing a space for reflections means those same models become vehicles for the transformation of mental models, of moving through the slow, logical, rational space of System 2 thinking [18].

A number of theories suggest that this reflection is where true learning happens, that when people are confronted by something that does not align with their worldview, they must then have the space to reflect and consider, so that their mental model can be updated (and hopefully improved) by what they have learned [123]. Key to this reflection is the role of **feedback**, at various levels [10]. That feedback comes in the form of information, whether that was sourced from a question from a facilitator, a viewpoint shared by a peer, or an unexpected statistic. Feedback shows what went wrong and why, and it is that mistake that allows for learning to happen, for neurons to fire, for the grooves to deepen in the mind [124].

One of the ways to internalize feedback is to create a mechanism, in collaboration with stakeholders, by which feedback can be provided, such as goals. In short, facilitators can and should guide the participants to choose their own feedback through a goal-setting process. However, goals are only made meaningful if it is the participants who choose them from the outset. That way, success or failure is dictated by the measurement created and owned by the people in the room. Setting out a measure or goal at the outset provides a benchmark to indicate whether or not success was achieved, providing clarity on what the group is working towards and how it is going to get there. This should be done at the beginning of the process and should occur for both the group, perhaps as part of the collective rule-setting, and for individuals, so that they can internalize and own their personal stake in the process.

Goal Framing Theory provides a template for the types of goals to create, as those in the environmental field are often more focused on the abstract 'normative' goals of sustainability, where it is difficult to know what the 'right' or 'best' thing to do might be [71]. To turn these into more concrete actions, and therefore more likely to be followed, we should link abstract concepts, such as sustainability, into a specific behaviour, such as recycling all glass and aluminium [71]. Using goal setting at the outset of the exercise, to have stakeholders create their own internal mechanisms provides a way for stakeholders to receive feedback (and therefore increase the chances of learning) and for them to buy into the process [71].

These goals provide a relevant form of feedback and more importantly, provide a source of reflection for the group and for individual participants [125,126]. What went well? What went wrong? Furthermore, why did that occur? The 'why' provides the key to reflection, encouraging participants to dig into the reasons behind something occurring, which is where feedback can occur and lessons can be learned and internalized [11,124,127]. The key is to make this feedback either neutral (from the facilitator's perspective, any sort of 'grading' is to be avoided) [128] or internally driven by the stakeholders, who can do so by setting out their own personal goals at the beginning.

One way to promote reflection and to encourage an open mind from the outset is a practice known as '**Memento Mori**'. Memento Mori dates back to ancient stoicism, and literally translates as a 'meditation on death'. The exercise is designed to consider one's mortality and inevitable demise as a way to clarify one's values, one's purpose, and what is truly important. Variations of this have been used in educational settings, and include

writing one's own eulogy, visiting a graveyard, and the thought exercise of only being given five years to live. The purpose of such a morbid exercise is to create 'unfreezing' in stakeholders; to present a shocking scenario to force people to reconsider their daily lives and habits, to step outside of their routine and consider what a new and better path forward might look like [123,127]. It also does not have to be death: it could be a major fire or the sickness of a family member. Done properly, these grim hypotheticals seek to mirror the role of crisis in asking the question of everyday procedures and creating a window of opportunity for change [123,127,129,130]. Furthermore, it has been used in PM as part of a scenario analysis, in which practitioners gave participants extreme scenarios, such as drought or a pest infestation, designed to 'shock' participants with decisions and situations that could plausibly occur in real life, increasing their engagement and opening them up to learning [131,132]. However, this extreme scenario (death or otherwise) is not widely used, and it could be us as a tactic—particularly at the beginning of a PM exercise—to encourage the type of reflection needed to internalize learning.

Regardless of how it occurs, reflection is a necessary part of the learning process [9,133]. This reflection can be personal, through goal setting, or it can occur at a community level, creating a common vision, setting priorities, and then evaluating how that process has been achieved [10]. It is the job of the facilitator to consider these various levels of reflection and provide a path forward for stakeholders to receive feedback, internally and externally, so as to achieve the transformation of mental models sought by the PM process [45,134].

3.5. Being Consistent

3.5.1. The Barrier

Finally, consistency refers to the practices and standards used to successfully facilitate PM. Practitioners seek consistency in the hopes that a well-documented, systematic, and organized process can be replicated and applied to other cases, to make comparisons, to evaluate, to learn, and to ultimately improve the PM process. Usually, this is seen as a barrier of methodology or technology, as there is a recognized lack of standardization and/or best practices to "facilitate PM processes in a fair, transparent, and scientifically sound manner" [17]. There is a noted lack of "conceptual, procedural, and technological designs. . . for effective stakeholder participation, enhanced public understanding of socio-environmental dynamics, and clearer recognition of how such understanding connects to environmental and social improvements" [48]. However, we consider consistency to also be a human barrier because no two stakeholder groups are the same, meaning that every PM exercise is unique, and yet we still seek to learn from each exercise so as to improve and apply the lessons learned to our next PM process. ROE does provide a starting point for the PM process and its findings to be tracked (and therefore improved upon), and it should answer the larger question of how does this process and model outcomes apply to other cases with different stakeholders.

This is the question of specificity versus applicability [17]. One of the disadvantages of PM is that it involves a large investment of time and resources. It is a waste if the knowledge gained though one PM process is limited to only the issue and stakeholders involved, if there is no transfer value for other PM processes, and in turn if there is no learning incorporated from the other, previous PM processes.

Each PM process may necessitate something ranging between specificity and applicability. An ideal PM possesses enough specificity to cater to the unique situation of the participants and the system in focus, while remaining general enough to apply lessons learned to other, similar scenarios in the hopes of addressing broader challenges. Thus, the challenge of consistency means we seek to make PM systematic, repeatable, and transferable, which is difficult to achieve with the uniqueness of each PM application and the diversity of stakeholders [42].

3.5.2. Some Solutions

Finally, consistency is perhaps the hardest challenge, as people are unique, situations are unique, and no PM process is likely to be the same. Even if we follow the exact same steps or work with the same group of stakeholders, that is unlikely to guarantee the same outcomes. However, we can be consistent in the principles we use to guide a PM process and to guide our communication with stakeholders. The ones we offer here provide one way to consider this process and the implications it holds for the way we act before, during, and after PM.

A recognized way to encourage consistency within the field is through records or **evaluation**. There have been numerous calls for a "Record of Engagement" (ROE) within PM to both standardize the design and reporting of any PM exercise [83,135], particularly among those who recognize the role of learning as a part of the process, and the need to account for it in order to fully appreciate and evaluate any PM process [38,48,83,135,136]. Glynn et al. (2018) explicitly mentioned accounting for beliefs, biases, heuristics, and values, but do not explicitly mention a framework to capture those unavoidable elements of working with people [83]. However, Cockerill and colleagues, in their follow up, take "further steps to explicitly include documenting biases, values, beliefs and emotions into the historical record" by laying out prompts for the content and the rationale for decisions made during PM, including specific questions on the 'affective atmosphere' and the 'emotional/cognitive state of participants' [135].

One promising development in this regard of 'affective atmosphere' and the 'emotional/cognitive' state of participants is the Rich Elicitation Approach of LaMere et al. (2020), which proposes to use the direct building of mental and conceptual models with stakeholders (i.e., What are the system's components and it's relations?) and indirect methods which involve coding transcripts of conversations with stakeholders to see what variables and relationships may be 'hidden' in the text [45,135]. Clear documentation of this coding and its impact on any subsequent model would be paramount, in keeping with good qualitative coding practice [137]. Where further developments could be added is in using that same 'indirect' documentation with methods such as those used by Radinsky and colleagues (2017), where they visually represent interactions between stakeholders during a PM exercise, including a representation over time of topics discussed and 'mapping' who spoke to who during a particular workshop by Moallemi et al. (2020) [51,138]. While not yet a widespread practice, PM researchers have begun to develop a number of methods that seem capable of creating a more consistent measure of both process and outcome in a PM exercise.

In addition to these developments within PM, researchers can also draw from practices based in psychology to better measure a change in stakeholder behaviours and mindsets over the course of PM. Smajgl and Ward (2015) and their challenge and reconstruct learning framework [139] draw from the Theory of Planned Behavior and use psychometric testing—both pre- and post-workshop—to measure a change in systems thinking, while as mentioned, LaMere and colleagues (2020) also examined explicit and implicit discussions from stakeholders to devise their models, in recognition of distorting biases that may keep stakeholders from recognizing the gap between what they say versus what they think [45]. Both approaches offer a way to learn, measure, and account for biases, and could be supplemented by additional **psychometric scales** to measure concepts of interest, such as systems intelligence, psychological needs, or autonomy (based on Self-Determination Theory), or a measure of their values, beliefs, and norms [140,141]. Pre- and post-testing through questionnaires does not tell the whole story of an exercise, but it can supplement and support findings.

Additional methods from psychology include those drawing from personal construct theory [142] to draw out further explanation and insight from participants and to prevent a 'misalignment' from what is physically represented on a model versus what understanding exists in stakeholder's minds. Those tactics include a Salmon Line, Pictor, and the Role Repertory Test as a way to "provide in-depth insight into personal experience, to establish

a 'democratic' relationship between the researcher and participants, and to represent the participant's 'voice"' all of which benefit the relationship between PM practitioners and stakeholders, and improve the PM process (methods further described in [143]).

On consistency, it is equally, possibly even more important to track the behaviour and consistency of the facilitator across PM exercise as this may be one of few constants across unique PM contexts and stakeholders. While a body of work that deserves its own paper entirely, researchers in the broad fields of qualitative research and social science have been wrestling with these questions of specificity versus applicability for decades, with many concluding that while there is no one-size-fits-all solution, transparency and tracking in what decisions the researcher is making, the justification for those decisions, and the impacts of those decisions is widely recognized as an excellent start [144–147]. We identified a few tactics here that may be of use, both within and outside the PM field, but there are undoubtedly more available to researchers. Regardless of the source of insights, what is clear is that bringing our categorization of human barriers into these developed processes for PM can encourage an explicit accounting of people's irrational behaviours, at every stage of the process.

Table 1. Tools and resources that can be used to overcome the five barriers identified in this review.

Barrier	Solutions
Subjectivity and bias	• Awareness of cognitive bias [59] • Framing [72] • Pre-modelling [76]
Managing conflict	• Agreed purpose and shared value, such as collaboration [32,77] • Creating psychological safety [81] • Practising active listening [94,95] • Role play [57] • Rapaport's rules [96]
Dealing with power	• Social network analysis and mapping [103,104] • Critical questions [108,109] • Guidelines and rules [77] • Red Team [110,111]
Communication	• Dialogue [9] • Teaching metacognitive skills, such as critical thinking [121,128] • Encouraging reflection before, during, and after the workshop [9,10,124] • 'Grim' scenarios [127,131] • Giving feedback [125,126,128] • Goal setting [71]
Consistency	• Evaluation through records of engagement [48,51,83,136,138] • Psychometric scales as pre- and post-questionnaires [139–141] • Personal construct theory methods (Salmon Line, Pictor, Role Repertory Test) [142,143]

3.6. The Importance of Transdisciplinary Insights

The bottom line is that the mere presence of humans (both as researchers and as participants) presents certain barriers to implementing successful PM processes. First and foremost, it is the nature of humans to be *irrational and biased*, bringing perspectives and values to the PM process that can distort 'reality' to suit their purposes and potentially limit the effectiveness of the process. While PM has yet to fully and systematically integrate this understanding of our own irrationality (although there are efforts underway, see [61]), there is increasing recognition that these things must be accounted for and managed as a part of any scientific effort involving people. Then, the subjectivity of people creates *conflict*, as tightly held values are inseparable from the process, and it may be difficult to separate people from those values and from the institutional, cultural, and power hierarchies they belong to. Ensuring the process recognizes entrenched forms of *power* and creating a space

where conflict can be managed is essential to ensuring a productive PM process. Choosing *communication* strategies to address these barriers is no small task as PM must be able to effectively capture the complexity of social-ecological systems, visualize the problem to promote understanding, encourage learning, manage BBHV, and ultimately empower individual stakeholders to have a collective and systemic impact. It is then crucial to make these design and facilitation choices in a way that supports *consistency* in facilitation across PM exercises, both so cases can be compared, and so findings can be applied with other stakeholders elsewhere so all involved in PM may continue to learn from each other. The five barriers we identified here recognize that humans have some common cognitive and behavioural traits. Other fields of study, such as education, behavioural economics, neuroscience, and psychology, among others, present solutions on how to deal with these barriers, and drawing from them may present one way to consider the design of any PM exercise in such a systematic and principled way.

Participatory modelling stands to gain from a systematic incorporation of the science on how to overcome the five identified barriers throughout a stakeholder engagement process, leading us to the fields of social learning, behavioural economics, and others, who have made a study of understanding the way people think, act, learn, and adapt, as individuals and as groups [38]. By drawing from these fields, PM can develop more meaningful, targeted and deliberate strategies of communication designed to account for how to transform the mental models of stakeholders, thus improving the likelihood of an effective process leading to shared understanding and ultimately, positive change in a given SES (see Figure 3).

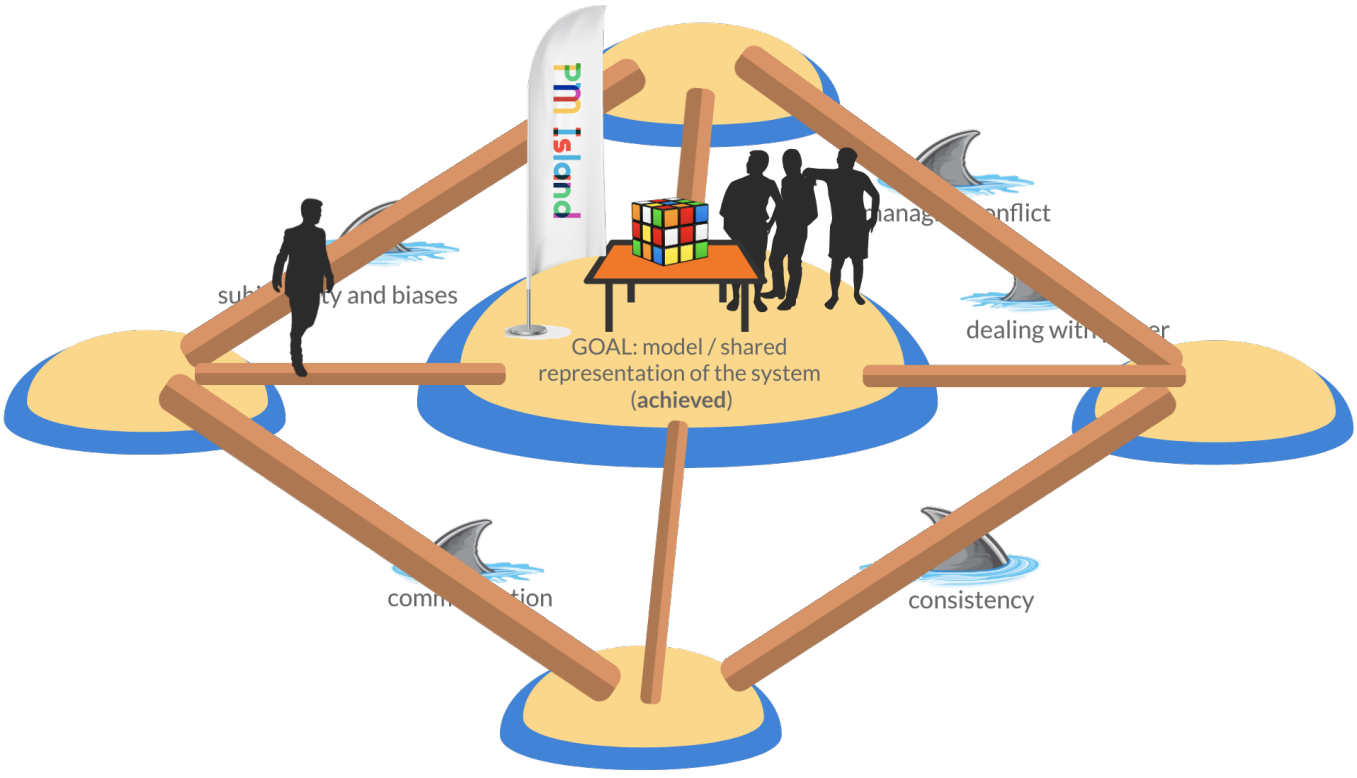

Figure 3. Using transdisciplinary insights to help 'bridge' contrasting mental models together and sidestep human barriers, PM can more effectively bring people and their mental models together for a better and shared representation of the system.

4. Going Forward

PM is an established field that already delivers benefits to practitioners and stakeholders, and is already seeking to address the big questions around how to better manage SES. Despite several decades in the field, PM is still growing, still learning, and still changing.

More PM practitioners and experts are recognizing the role of people and the need to account for their values, beliefs, and worldviews [18,38,69,83,148]. The conceptualization of transforming 'mental models' as a crucial part of the PM process is promising, and what we have offered here, as an exploration and a call to arms, are better techniques, drawn from other disciplines, to draw out those mental models from stakeholders and to steer them towards the transformation needed in accordance with the key principles of SES management [15,69,89].

By no means are the 'human' barriers we presented here exhaustive. Nor should the fields of inquiry be limited to those we have named. However, as science delves deeper into our human 'irrationality' (see, for example Stanovich 2013 [149]), we deepen our understanding of how people think, learn, and behave as people. Those lessons, regardless of their field of origin, should be incorporated into PM as a way to increase our chances of transforming individual mental models, collective understanding, and the ways we manage our SES. The practices and examples we have laid out here are a start, and this paper and others present a strong case for the continued pursuit of a deliberate and purposeful PM process truly designed for the people at the centre of the process in all of their wondrous flaws.

Although we separated and categorized these barriers, they, like people, cannot so simply be boxed up in a black and white fashion in reality. These barriers blur into one another, and each is co-dependent on the other. However, while the categorization we present here may not reflect the messiness of reality, it can still be useful to our PM practitioners. We offer these categorizations in the spirit of seeking to synthesize the barriers of working with humans as a part of PM, as that has yet to be comprehensively drawn together in the PM literature, and to serve as a call to arms for others to utilize a transdisciplinary approach to solving the problems presented by people. Through the transdisciplinary approach we demonstrate, we describe a number of practical tools, and we hope others both find these useful and seek to add to such a list by finding more tools that exist out there.

We believe the following key areas should be explored in future research:

- Experimental research should seek to 'test' the efficiency and effectiveness of the solutions we presented above, both in their ability to impact stakeholder learning and in assessing the trade-offs in the time, resources, and expertise needed to successfully implement them. The challenge of assessing such impacts should not be understated, as isolating variables in social science, particularly with smaller sample sizes common in PM efforts, is difficult. However, starting from results from other fields, as done herein, and implementing their experimental methods (the work of Cialdini and colleagues is a great example) is one area that should be explored further [63,66,150].
- Collaborative efforts with experts from multiple disciplines should continue and expand in pursuit of transdisciplinary solutions to promote stakeholder learning and SES change. While bringing experts and researchers from various disciplines does not guarantee success (and often creates its own headaches), the potential for truly innovative and discipline-spanning solutions is immense. Combining expertise and knowledge from psychology, neuroscience, education, action researchers, negotiation, behavioural economics, and other fields creates the possibility for solutions to emerge that are so much greater than the sum of its parts.
- Stakeholder values, beliefs, and biases shape their worldview and therefore their actions. Cognitive biases tell all of us something about the world is 'true' when reality may say differently. Acknowledging the role that these cognitive biases play and more explicitly incorporating strategies to bring awareness to them and limit their impact can and should be an accepted part of PM facilitation and practice. Research that focuses on addressing a specific bias, say confirmation bias, and exploring how that can be qualitatively and quantitatively limited is a promising area for the future.
- Various authors have called for recording the results of participatory modelling exercises as a way to both learn from past experiences and improve the practice going

forward [48,83,135,136]. Work by [151,152] also provided promising developments in PM, investigating the PM process as a series of decision pathways that are influenced by the people involved in the process. Together, the authors advocate for a reflective approach to documentation and decision making and the need to consider alternative pathways during the modelling process to reach the best outcomes. The authors also note the influence of the "human factors" on extending beyond PM to management actions, and propose practices such as reflection, de-biasing, red team, and the necessity of documentation as part of diagramming decision pathways of PM that can complement the building of the model [151,152]. Regardless of whether it is a 4P Framework, Records of Engagement, the Protocol of Canberra, or a new format, the PM community should seek to move towards the increasing standardization of documentation of the process, as has been done with agent-based modelling and the ODD framework [48,83,135,136,153]. Total consensus is unlikely, but there is still value in moving towards a more widely used evaluation framework. There are outstanding questions about the format, understandably, but we hope that the outstanding issues we presented thus far demonstrate the importance of considering the 'people' at the centre of the process and the necessity for deliberate and proactive planning on the 'how' of their learning as a result.

To address problems of SES, we need solutions that recognize the complexity and uncertainty of the world we live in. We need transdisciplinary, systemic, adaptive, and participatory approaches. We need to understand how central individual and social learning are to the necessary transformation. PM offers a promising way to address that, but it also has much to learn from the fields devoted to understanding how people think, learn, behave, and decide. We hope that others take up this call to arms and further explore the areas we have shown herein, and to reach out to other areas we have not named.

Author Contributions: Conceptualization, D.C.K. and J.C.-R.; methodology, D.C.K.; investigation, D.C.K.; writing—original draft preparation, D.C.K.; writing—review and editing, D.C.K. and J.C.-R.; visualization, J.C.-R.; supervision, J.C.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by The Australian Research Council (ARC) Discovery Project grant number DP190101584.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We acknowledge The Mulloon Institute, Chilean Department of Primary Industries (CORFO), Chilean Directorate of Water (DGA), and the Natural Resources Access Regulator (NRAR) in Australia, who provided the institutional support and testing of participatory modelling methods with relevant stakeholders and divisions which inspired this review.

Conflicts of Interest: The authors declare no conflict of interest.

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