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Systems Thinking as a Catalyst for Climate-Cognisant Sustainable Land Use Planning: Insights from Regional Victoria, Australia

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ABSTRACT:
Amidst escalating climate change challenges, effective land use planning and decision-making are crucial for nurturing resilient and sustainable landscapes. Decision-makers often struggle with unintended consequences due to the intricate system dynamics, compounded by fragmented information and divergent stakeholder perspectives. This research integrates science, stakeholder engagement, and systems thinking to navigate the complexities of land use planning in response to climate change. We develop a decision-making framework for climate-cognisant sustainable land use planning, incorporating systems thinking principles. The framework uses validated expert system models to assess climate change impacts on agricultural land use. Through collaborative engagement with end users, it is refined to address specific regional challenges and opportunities. Applied within a case study in Victoria, Australia, and generalized for broader contexts, the framework provides a practical, systemic-intervention-driven process for better regional planning decisions amid evolving climate complexities.

Keywords: Climate Change, Land Use Planning, Systems Thinking, Decision Making, Stakeholder Engagement

1. Introduction

1.1. Land Use Planning in Australia as a 'Wicked Problem'

The term 'wicked problem' was first introduced by Rittel and Webber in their article entitled "Dilemmas in a General Theory of Planning", which provided a framework for planners on how to distinguish between tame and wicked problems (Rittel & Webber, 1973). Wicked problems are characterised by their complexity, open-endedness, and the involvement of multiple stakeholders with often conflicting perspectives. In addition, wicked problems have ever-changing requirements that are often difficult to recognize; and lack clear definitive solutions.

Wicked problems are particularly evident in regional contexts, where multiple drivers of change interact in complex and often unpredictable ways. A region's land serves diverse purposes, including agriculture, pastoralism, nature, heritage conservation, and forestry, each accompanied by distinct land tenure patterns such as public and private ownership,

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leasehold, and Indigenous land tenures(Howling & Pulsford, 2018; Thackway, 2018). Therefore, regional land use planning exemplifies such a wicked problem, presenting a complex, multifaceted challenge. The complexity of regional land use planning is further compounded by the multi-scalar governance system, where Federal and state governments set policies, and coordinate and invest in regional and local planning (Wallis & Ison, 2011). With a shift towards regional delivery of federal and state responsibilities and funding, planning has become increasingly complex (Colloff & Pittock, 2019; Patterson et al., 2013). The resulting system presents significant challenges for Natural resource management (NRM) governance, particularly in balancing competing priorities, allocating resources and implementing plans effectively.

In a regional planning process, land uses should be allocated to meet multiple and sometimes incompatible community demands and expectations. This task is exacerbated by conflicts arising from differing interests among institutions, groups, and individuals vying for control over land resources. Such conflicts are particularly acute in regions where land uses overlap and compete for limited resources, exemplifying the concept of a 'wicked problem'. To address these challenges effectively, decision makers require adaptive management strategies that allow flexibility and iterative learning as conditions change. A successful example of this is the Murray Darling Basin Plan in Australia, where water management strategies are continuously adjusted based on environmental monitoring and stakeholder feedback, helping to balance ecological needs with agricultural demands (Thompson et al., 2019). One of the interesting aspects of the Murray Darling Basin Plan is the implementation of an entirely new governance structure, which is distinct due to its broad geographic scope, complex intergovernmental collaboration, strong legal framework, emphasis on environmental sustainability, and extensive stakeholder engagement. This sets it apart from other water-related agencies that typically operate within more limited scopes and with different priorities. Therefore, depending on the scale of the region of interest, or the complexity of the context, integrating new ideas into existing governance structures may be feasible, or it may be necessary to develop bespoke governance structures to avoid legacy barriers and constraints.

Fragmented Information

In this intricate environment, Decision makers need to foresee potential impacts and avoid unintended consequences of their actions, in spite of fragmented and uncertain information. (Bosch et al., 2013). The complexity of natural systems, combined with scattered knowledge across scientific publications, reports, databases, and in people's heads(Banson et al., 2015; Maani, 2013). This fragmentation makes effective decision-making challenging, as different disciplines focus on distinct aspects of the problem. Biophysical researchers explore how ecosystems operate when disrupted by various environmental factors, whereas social scientists investigate the root social and institutional dynamics that influence patterns of sustainable development. (Bosch et al., 2013; Dovers, 2018). Economists, in turn analyse the financial implications and economic viability of different land use strategies. However, integrating these research findings into actionable knowledge remains problematic without a holistic approach encompassing ecological, social, and economic dimensions.

Divergent Stakeholder Perspectives
Each stakeholder brings a unique viewpoint on management systems, shaped by their specific objectives (conservation vs production) and mental models. These mental models are shaped by differing driving forces at various scales (Lalani et al., 2023; Walters et al., 2019). At one end of the spectrum, global economic trends and international policies shape the broader context in which resource management decisions are made. These macro-level forces often prioritize long-term planning for issues such as climate change mitigation and biodiversity conservation. In contrast, at the local level, individual land managers and resource users often face more immediate financial pressures. Their mental models are shaped by the day-to-day realities of maintaining livelihoods, meeting financial obligations, and navigating local market conditions. For these stakeholders, short-term economic viability may take precedence over long-term environmental considerations, not out of disregard for conservation, but due to the pressing nature of their immediate needs. This disparity in perspectives and priorities creates a significant challenge for effective communication and collaboration among stakeholders. The lack of mutual understanding of these diverse mental models can lead to misinterpretations, conflicts, and ineffective policy implementation.

This uncertain, fragmented and conflicting picture of natural resource management can result in decision-makers continually dealing with symptoms rather than the underlying causes of management problems and lead to non-linear system responses, tipping points, and spillover effects (Wang et al., 2022). Thus, there is a need to integrate information surrounding land management issues in a systematic way.

1.2. Climate uncertainty as a 'Super wicked Problem'

The concept of 'Super wicked problem' is an extension of Rittel and Webber's (Rittel & Webber, 1973) 'wicked problems' seem to stem from frustration over the short-sightedness of policymakers in combating global issues like climate change (Grant et al., 2019; Levin et al., 2012). Super wicked problems extend beyond the characteristics of regular wicked problems by incorporating additional complexities. These problems are marked by (i) significant time pressure/a feeling that time is running out. (ii)They also lack a central authority, as no single entity or governing body possesses the comprehensive power to address the issue. (iii)Problem solvers are problem makers, creating a paradoxical situation where stakeholders seeking solutions are simultaneously part of the cause. (iv) Super wicked problems involve irrational discounting of the future, where certain policies or actions may illogically impede future progress or potential solutions.(Levin et al., 2012) These additional features compound the already challenging nature of wicked problems, making super wicked problems even more intricate and difficult to resolve.

Land use planners and resource managers must now grapple with projections of future climate scenarios that carry significant margins of error and variability. This uncertainty manifests in multiple ways: shifting precipitation patterns may alter water availability for agriculture and ecosystems; changing temperature regimes could affect crop viability and natural habitat distributions; and increased frequency of extreme weather events may pose new risks to infrastructure and land use patterns. The long-term nature of climate change also clashes with the typically shorter timeframes of land use planning cycles, creating a mismatch between the scales at which decisions are made and the scales at which their consequences unfold.

Uncertainty in climate change is compounded by a decision making environment burdened with involvement of number of institutions and stakeholders, alongside shifts in policies, regulations, leadership, government structure (Maani, 2013). As a result, decision makers and stakeholders must continually adapt to these new challenges and emerging opportunities.

Addressing these challenges requires collaborative frameworks that actively involve diverse stakeholders in a transparent and inclusive manner. Adaptive co-governance serves as a promising approach which share similarities with the systems thinking approach deployed in this study, blending science, policy, and community inputs within a flexible management system. This model supports ongoing adjustments to strategies, informed by real-time environmental data and continuous stakeholder feedback, enhancing resilience amidst uncertainty. In the Niagara region of Canada, adaptive co-governance has been applied as an innovative approach to tackle the complex challenges posed by climate change (Baird et al., 2016).

1.3. Why Systems thinking?

Systems thinking is a transdisciplinary approach that addresses the root causes of challenges by viewing problems as parts of an overall system, in contrast to the reductionist linear approach synonymous with 'quick fixes' to specific parts. The traditional reductionist approach leads to siloed thinking in which a fix 'here' simply shifts the problem 'there' and 'organisational myopia' in which a fix 'now' gives rise to the need for a much bigger problem to fix 'later' (Banson et al., 2015; Bosch et al., 2013). In contrast, systems thinkers frame a problem in terms of seeing the whole forest instead of focusing a particular tree (Grant et al., 2019b).

It encourages decision-makers to the interconnectedness of various elements within a complex system, recognizing that "you can't just do one thing and that everything is connected to everything else". (Ackoff, 1974; Mingers & White, 2010). Systems thinking enables decision-makers to compare impacts across various scenarios and analyse trade-offs between different options. By facilitating "What if?" questions, it allows for the exploration of potential outcomes and helps avoid the creation or transfer of problems while pursuing solutions, and enhances the capacity to respond to unintended consequences (Kotir, 2019)

Systems approach in this research adapts aspects of soft systems methodology (systemic intervention) and hard systems methodology (system dynamics) (Ackoff, 1974; R. Ison, 2010; Mingers & White, 2010). This approach is designed to enhance the understanding of decision-making processes and foster system thinking skills among modelers and end-users (Moallemi et al., 2020). The research leverages participatory system dynamics modelling, which has gained prominence due to its ability to integrate stakeholder input into the iterative modelling process. Many studies have concluded that co-creation, implicitly or explicitly through embedding stakeholder input into the iterative process of modelling and combining computational and human capabilities interactively adds flexibility to the problem solving process and knowledge diversity, which in turn helps to minimise model rigidity, accommodate multiple perspectives, promote social learning, and promote adaptability in policy decision making (Kotir, 2019; Videira et al., 2014; Voinov et al., 2016).

2. Objectives

The research aims to develop additional information and thinking frameworks to streamline the land use policy planning process by addressing the following issues.

Data and Information: Develop user-friendly data platforms and systems that facilitate easy access and interrogation of land use information, with a particular focus on integrating fine-grained local knowledge with coarse-grained broader datasets.

Decision Transparency: Integrate techniques and methodologies that enhance transparency in environmental decision-making, focusing on effective ways to communicate complex land use information and decisions to non-technical experts and stakeholders.

Science vs Policy: Create more pragmatic and policy-relevant models through a participatory approach that bridges the gap between scientific knowledge and policy implementation. This objective aims to bring together modelers, decision-makers, and diverse experts to ensure research findings are effectively translated into actionable land-use strategies.

Compounding Decisions: Develop a framework to identify and avoid unintended consequences of land use decisions.

3. Case study Region

The research follows a case-study approach and therefore focuses on the North Central Catchment area of Victoria, Australia. The North Central Catchment region covers approximately three million hectares representing 13% of the State of Victoria. There has been significant modification of the North Central Catchment landscape since the late 1800s from the introduction of European agricultural techniques and gold exploration and mining. The north central region has been extensively cleared, particularly on the flatter more fertile plains, where less than 30% native vegetation remains(NCCMA, 2020).

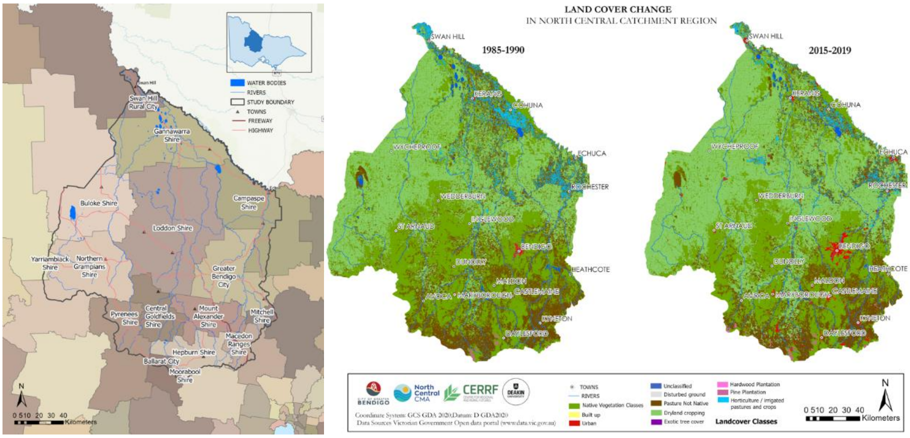

Figure 1: Case study Region (Left), Land use change in the Region (Right)

The region sustains diverse agricultural enterprises, from livestock grazing in the uplands to cropping, mixed farming in the foothills and Irrigated agriculture is concentrated in north of the region on the Riverine Plains. In the southeast part of the region, predominantly south of Bendigo, the demographics continue to change with an increasing demand for rural residential living (lifestyle, hobby farm) development(NCCMA, 2020). With this expansion comes a wide range of landholders new to land management. Agriculture may remain the dominant land use, but primary production is not the principal focus for many landowners. There are typically more landowners with diverse interests, increased numbers of smaller land parcels, a large variety of land uses/enterprise types, more non-resident owners, and more property owners with limited understanding of natural resource management (NRM) and connection to existing NRM networks(Bendigo, 2021; Curtis, 2018). Combined with the aforementioned characteristics (diverse mix of land-uses, history of land-use change, climate impacts) and the willingness of regional stakeholders to embrace novel approaches and to collaborate in the research, the North Central Catchment region is the ideal case study location for research of this type.

4. Research Design and Findings

The research framework, adapted from Social Learning for Integrated Management (SLIM) model (Collins & Ison, 2009; R. L. Ison, 2004), identifies four interconnected variables crucial for addressing complex natural resource management issues: stakeholder engagement, facilitation, ecological constraints, and institutions and policies. These variables interact dynamically, influencing how environmental issues are understood and addressed through social learning processes. The focus of this paper is on the first two phases (Stakeholder engagement and facilitation), with some discussion of the third phase (knowing and learning). A future paper will explain the other phases. It is important to note that this is an ongoing research project, and we will continually engage with stakeholders throughout the process. This iterative approach allows for the incorporation of new insights, the refinement of our understanding, and the adaptation of our strategies as we progress.

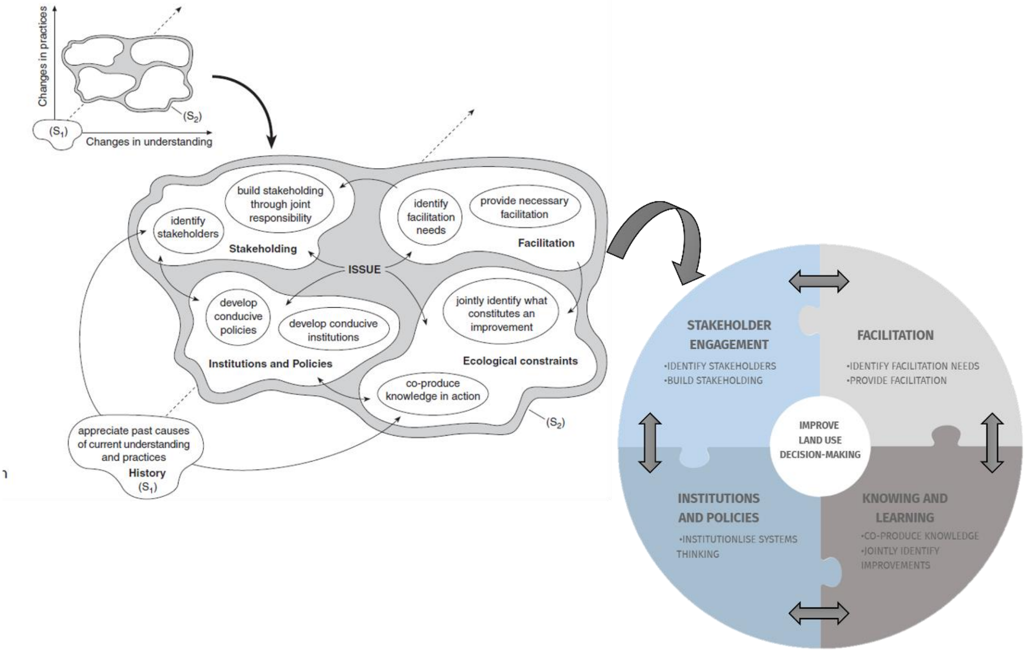

Figure 2: Framework Adapted from (R. L. Ison, 2004)

4.1. Phase 1: Stakeholder Engagement

The research inquiry conducted from 2021 to early 2024, was centered on a project titled '*Bendigo-North Central Land use and Climate Adaptation project (BNCL-CAP)*'. This research was a collaborative effort between Deakin University Centre of Regional Rural and Futures, City of Greater Bendigo and North Central Catchment Management Authority. The starting point of this meta inquiry was establishing a steering committee engaging over 20 people from different NRM organisations to guide the project and ensure local relevance through alignment with current and upcoming opportunities, effective strategic positioning, and targeted communications with key agencies that would support broader endorsement and support for the research outcome.

This initial phase enabled the researcher to gain a deeper understanding of the regional context in which NRM planners were operating. Relationships were iteratively developed throughout the research partnership via face-to-face meetings and online both in the region and centrally feasible. Throughout the research, interdisciplinary engagements were maintained between experts from various disciplines, organisations and local communities. This approach served to value diverse perspectives and knowledge systems, enhance understanding of local systemic dynamics, and foster stakeholder investment in research activities. The university participants acting as the research team took on roles as facilitators, co-designers, and co-inquiries within the collaborative framework. This approach aligns with the concept of researchers as part of an inquiry system, as illustrated in Figure 3 (Grant et al., 2019).

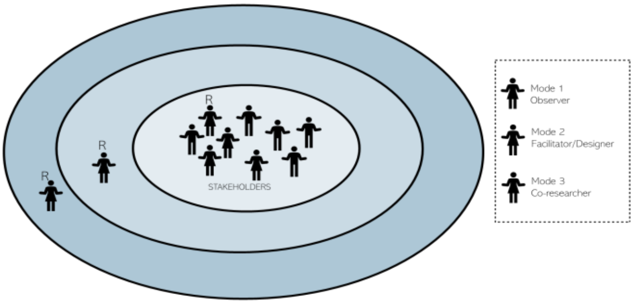

Figure 3: Researcher in an inquiry system Adapted from (Grant et al., 2019)

Data collection employed conventional social research methods, including focus groups and interviews conducted across the regional organizations, participant observation during meetings and events, and process documentation to capture insights and interactions. The research adhered to strict ethical guidelines, ensuring the confidentiality and anonymity of participants.

4.2. Phase 2: Facilitation

This process is underpinned by two activities; the development of climate projections for the target region and the creating of validated expert systems models (land suitability analysis) to assess the potential impacts of climate change on land use at a regional level. The output of the models are maps, which are ideal visual tools to engage stakeholders in discussion. Facilitation is essential for guiding learning processes and fostering systemic change among interdependent stakeholders. This collaborative approach helps stakeholders to develop a shared understanding and make informed decisions that support sustainable land use planning.

4.2.1. Climate Change Projections

Climate projections for the region were derived from the ACCESS-ESM1-5 global climate model and driven by Shared Socioeconomic Pathways (SSPs) from the Intergovernmental Panel on Climate Change (IPCC). Out of the five SSPs, SSP2-4.5 and SSP5-8.5 were used to derive climate projections for this project for the years 2041-2060 and 2061-2080. Historical climate data were derived from WorldClim Version 2.1 for the period 1970-2000. The baseline layer has a 1km^2 resolution to be comparable with the projection datasets. The variables analysed are temperature (mean, minimum, and maximum rainfall)

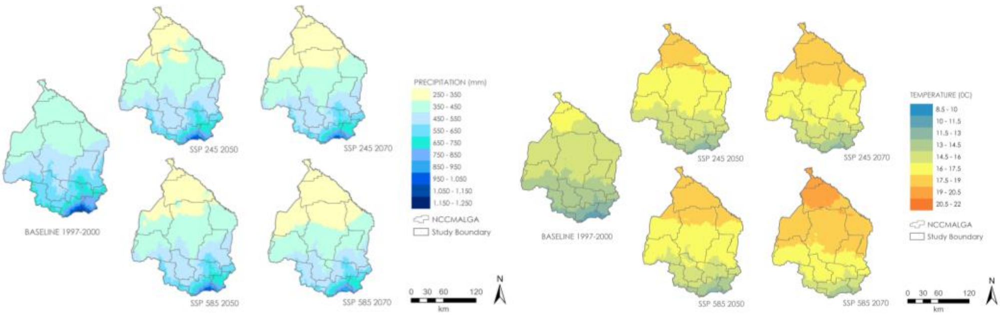

Figure 4: Annual Precipitation in the region (Left), Average Mean Temperature in the region (Right)

Climate projections for the North Central Catchment region indicate a trend towards drier and warmer conditions, with significant shifts in temperature extremes. Despite these changes, the climate transition in this area is expected to be less severe compared to other parts of Victoria. This presents an opportunity for the region to diversify its agricultural portfolio by introducing crops better suited to warmer climates.

4.2.2. Expert System models

The research employs Regional Land Suitability Analysis (LSA) as a core methodology. LSA evaluates the appropriateness of land for specific uses, offering a systematic approach to identify optimal land resource utilization and inform planning decisions. This method assesses how suitable land is for growing particular agricultural commodities, making it valuable for land managers, agriculturalists, and planners alike (FAO, 1976). By comparing current and projected future land suitability maps, the study aims to gauge the potential impacts of climate change on agricultural systems. This approach serves as a decision support tool and facilitates discussions on policy responses to anticipated changes.

The research team applied this methodology to analyse climate change impacts on various key commodities in the region, including pome fruits (apple and pears), stone fruits (cherries and peaches), pasture species, and forestry (sugar gum, Tasmanian blue gum). For illustrative purposes, the study presents only the LSA model output for Phalaris under baseline, 2050, and 2070 climate scenarios. In the figure 5, the green shades depict the areas ranked as having a 'high' and 'moderate' biophysical suitability (index in the range 70-100%), Yellow/Beige Colours depict the areas with 'low suitability' (index in the range 30-50%). Purple shades denote areas that are either permanently or temporarily unsuitable.

This analysis provides valuable insights into how climate change may reshape agricultural possibilities in the North Central Catchment region, informing adaptive strategies for land use planning.

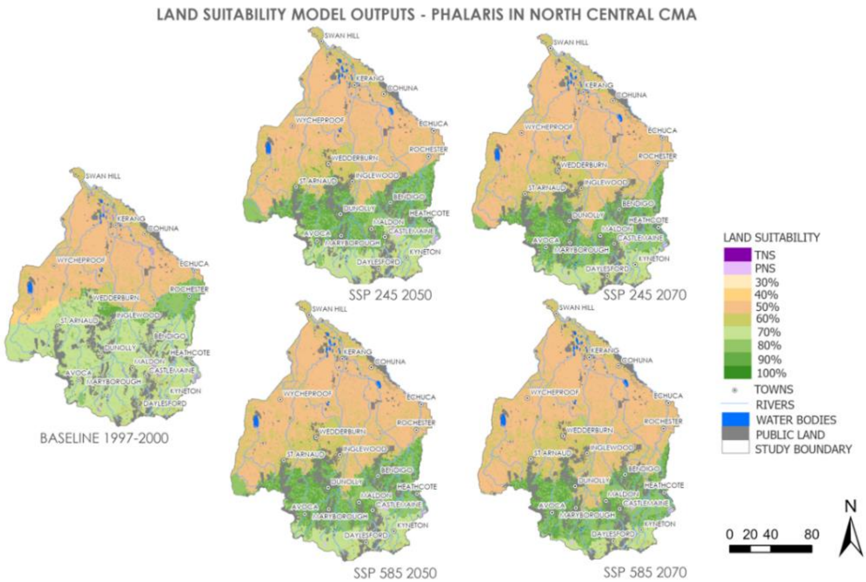

Figure 5: Land Suitability Output for Phalaris

4.2.3. Validation Phase

A crucial component of the LSA phase is validation via engagement with experts. In this context, experts are defined as anyone that has expertise and knowledge of the crop in question, or of the biophysical environment where it is being produced. As such, 'experts' ranged from researchers (agricultural scientists, agronomists and soil scientists, among others) that had worked in the region or with the specific crop, and farmers that produce crop. This validation phase involves an iterative process of refining initial systems maps and models through comprehensive stakeholder engagement. The validation is done via a combination of group workshops or individual conversations, with the aforementioned experts.

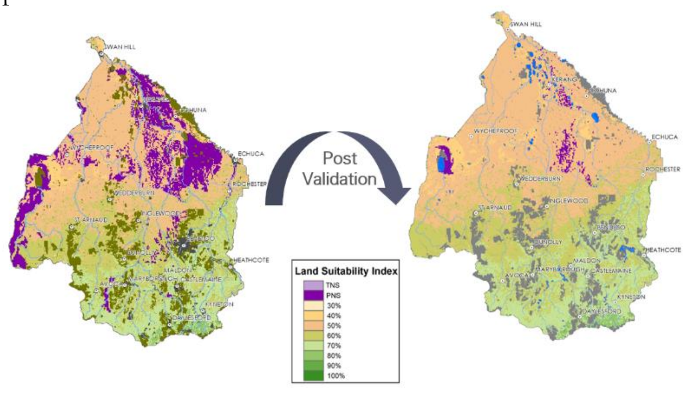

Figure 6: Pre and Post Validation of the process.

The research is currently repeating this iterative process to better understand the regional decision-making process. Land-use decision-making at the local and regional level is constrained by State-level planning law. Local authorities implement the laws but believe they have little capacity to influence them. As a result, climate adaptation as a component of land use planning can be ad hoc and ineffective. To understand where locally relevant data and information, such as the LSA model outputs, can best be used in existing and future (optimised) land use planning frameworks, systems thinking methodologies are being deployed again. This is ongoing research whose results are not presented below, but it is worth articulating here to contextualize the broader aims of this study.

First, causal loop diagrams are being developed via workshops and interviews with regional decision-makers. These diagrams are helping to better understand the decision-making process, how temporal and spatially explicit drivers of change like climate are considered, and how new information, data, and knowledge (such as the LSA outputs) can influence that process.

Second, the causal loop diagrams and LSA outputs inform the development of simple stock and flow models of the region. This allows the tracking of key resources, such as land for a land use, over time. In this way, it is possible to determine if existing or optimised decision-making frameworks facilitate sustainable use of a resource, given climate change or other test scenarios.

Third, looking at the causal loop diagrams and stock-flow models through a cybernetics lens, allows a better understand of the greatest leverage points where optimising decision-making or resource use can have the greatest impact.

5. Discussion

The expert-informed LSA outputs have given regional stakeholders, and particularly decision makers, an immediate picture of plausible likely land-use futures. The information is locally relevant because it is locally validated. Unlike similar assessments of climate impacts provided at the state level that are derived from highly aggregated and generic data, these maps provide fine-grained detail for farmers and planners alike.

This research underscores the transformative potential of systems thinking and stakeholder engagement in addressing complex land use planning challenges under climate change. The developed framework offers a practical, systemic-intervention-driven process for making informed regional planning decisions. The research framework emphasizes 'stakeholder engagement' as a key variable. This focus has allowed for a more comprehensive understanding of how different groups construct and promote their interests in relation to land use and climate change adaptation. The research approach, which combines scientific land use models with stakeholder engagement, demonstrates the power of systems thinking in bridging the gap between scientific knowledge and practical application. By involving local stakeholders in the research process, the study has likely increased the relevance and applicability of its findings to real-world land use planning challenges. This bridging of science and practice is particularly important in the context of climate change, where there is often a disconnect between global climate models and local decision-making processes.

Furthermore, the framework includes mechanisms for iterative learning and adaptation, enabling decision-makers to respond dynamically to evolving environmental conditions. Regular feedback loops and stakeholder engagement processes are embedded within the framework, ensuring that updates and modifications are grounded in real-time data and community input. By fostering a continuous adaptation process, the framework not only addresses immediate land use challenges but also enhances its long-term resilience and relevance in varying contexts.

While our study focused on the North Central Catchment area of Victoria, Australia, the core principles of this approach can be adapted and scaled to diverse geographical areas and socio-political contexts. Future research could focus on testing and refining the framework's application in varied geographical and socio-political contexts, further enhancing its scalability and global relevance

While the systems thinking approach offers significant benefits, it is not without challenges. The complexity of the framework and the need for extensive stakeholder engagement can make the planning process more time-consuming and resource intensive. Participatory modelling approaches can be further complicated by practical barriers such as the reluctance among researchers from different backgrounds to collaborate; potential conflict of interest among stakeholder cohorts; and stakeholder fatigue resulting from over-consultation. As the process extends over time, participants may experience diminishing enthusiasm or struggle to maintain consistent involvement due to competing priorities. To mitigate these challenges, planners can streamline engagement processes with clear objectives and timelines, utilize digital tools for remote participation, rotate leadership roles, and regularly communicate tangible outcomes. Implementing capacity-building programs and employing skilled facilitators can address power imbalances and ensure inclusive participation. There is also a risk of oversimplification when attempting to model complex socio-ecological systems. While the framework provides a useful structure, it may not capture all the nuances of unique contexts. However, ongoing refinement and adaptation of the framework will be necessary to ensure its continued relevance and effectiveness.

Evaluating the outcomes of land use decisions can be challenging, as the impacts of today's decisions may not become apparent for many years. Therefore, developing metrics that capture a range of factors to quickly indicate the effectiveness of these decisions is essential. In the short term, measures such as decision transparency and public engagement in decision-making processes can provide immediate insights into the success or shortcomings of current strategies. For the medium term, metrics could include sustainable land-use indexes or measures of resource-use efficiency, which might track biodiversity and water quality. Over the longer term, indicators such as changes in land values and regional job creation could serve as robust measures of the economic and social impacts of land use planning.

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