

## Developing climate services for use in agricultural decision making: Insights from Australia

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Climate change is one of the most urgent and wicked challenges of this century. Here, we reflect on the development of a national scale climate service for agriculture in Australia, and call for others to reflect on, and leverage, the collective wisdom of climate service delivery to improve outcomes across sectors. We use a case study of development of the My Climate View tool for Australian agriculture to discuss seven high-level principles for delivering climate science that we found useful to guide our work: Empathetic, Ethical, Inclusive, Iterative, Collaborative, Rigorous and Agile. Our discussion draws on extensive stakeholder engagement and our own experience across a large, and shifting, multi-stakeholder project team, to reflect on the challenges and opportunities of providing useful and useable climate projections. We highlight the need for further research in longer-term and 'end-to-end' climate adaptation, case study examples and new ways to evaluate climate projection tools.

"Climate services" can be defined along a spectrum from the delivery of data, such as the provision of weather and climate information to assist in decision making (Born et al., 2021), to supporting decision making through advice, decision-support tools, knowledge brokering, case studies, guidance, training and communities of practice (Palutikof et al. 2019). In this paper, we add to calls for more focus on furthering co-production of climate science information to support decision making and implementation (Lemos et al. 2014; Jagannathan et al. 2023).

Climate services are increasing in number, scope and scale (Webber 2019), yet there remain real challenges in matching the effectiveness of services provided with the scale of uptake and outcomes required (IPCC, 2023). Climate services are still often the result of 'data push' science and policy processes, rather than 'user pull' (Findlater et al. 2021). This

means climate services sometimes lack sufficient co-production with users, and while they may be informative to users, they may not readily translate into action (Hansen et al. 2019; Jagannathan et al. 2023). As climate change impacts increase, and adaptation becomes more urgent (Bergstrom et al. 2021; IPCC, 2023), there needs to be a shift in focus to supporting adaptations to climate change.

Globally, work has been done on climate projections for many decades, and services are continually improving and becoming better integrated into decision making at different scales and in different sectors. For example, climate information is now routinely and expertly integrated with agricultural crop models (Dainelli et al. 2022) used for emissions stocktakes (UNFCCC, 2023), and risk assessments (e.g. DCCCEW 2023a). Likewise, climate services have advanced significantly, evolving from primarily supply-side, top-down, one-size-fits-all approaches to a recognition of the need to support a unique and evolving community of decision makers and decision contexts (Jacobs and Street, 2020). There are many examples of climate services leading to useful outcomes, such as motivating adaptation, supporting funding decisions for resilience and decarbonisation initiatives, driving climate education and improving decisions around risk management (e.g. CBA, 2018; ARCC 2019; Singletary and Sterle, 2020; AEMO 2022). Nevertheless, the outcomes from this work are rarely transferred across sectors and scales, meaning resilience to climate change is lagging behind the required pace of change (Webber 2019; Findlater et al. 2021). Developing tailored climate services requires different resources, skills, and longer planning horizons than are currently typical in business decision making (Snow et al. 2024). Furthermore, despite the need for a high degree of interdisciplinarity in climate service development to facilitate

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broader scalability of outcomes (Daniels et al. 2020; Golding et al. 2024), this is still under-achieved (Larosa & Mysiak 2019; Vincent et al., 2020). To address the impact gap requires equal focus on the *process* of developing climate services (including building trust, sharing knowledge, challenging assumptions, adjusting timelines, and collective decision-making), and the *outputs* (Golding et al. 2024).

In the development of climate services, co-production with different groups is increasingly recognised as important to improve the process of developing tools and the outcomes, addressing the social values involved (inclusion, use) and technological innovation (design, accessibility). Decades of work has explored how more participatory models of science can answer questions around knowledge, power, science legitimacy and agency (e.g. Jasanoff 2004; Bremer & Meisch 2017; Carter et al. 2019; Norström et al. 2020; Kliskey et al. 2021). Simultaneously, technology innovation has explored how co-production can lead to products that are accessible to as many people as possible and better consider inclusivity in product design (Persson et al. 2014).

All this work demonstrates the importance of tailoring climate services to user needs (Wilby & Lu 2022; Vincent et al. 2020) and aligns with broader scholarly moves towards more ethical and socially responsible science (de Melo-Martín & Intemann 2023; Baldissera Pachetti et al. 2022), and literature on responsible innovation (Stilgoe et al. 2013). Co-production can take many forms, along a continuum of co-designing projects, co-developing the approach and co-delivering the results (Fleming et al. 2023). Different approaches have different levels of user focus and aspirations (Krauß, 2023; Bojovic et al., 2021). Co-production can also be viewed with different ‘lenses’, based on different academic traditions, logics and criterion for success (Bremer & Meisch 2017), or according to different pragmatic or transformative agendas (Hakkarainen et al. 2021; Jagannathan et al. 2020).

### Climate Services for Agriculture – a case study

To reflect on our experiences of some of these processes, this paper shares learning from the first phase of the Climate Services for Agriculture (CSA) program. CSA is a \$29 million program of work, conducted from 2020 to 2024, and funded by the Australian government through the Department of Agriculture, Fisheries and Forestry (DAFF) as part of the Future Drought Fund (FDF). CSA is a collaboration between the Australian Bureau of Meteorology and the Australian national science agency, CSIRO, as well as consultants and stakeholders who have participated in interviews, workshops, field days and other forms of engagement. ‘My Climate View’ is the program’s flagship product; a web-based tool that gives users past, seasonal and projected climate information all in one place, at 5 km<sup>2</sup> resolution across Australia. Users set their location and commodity or choose the ‘general climate information’ option to receive tailored information about the future climate for their location. The free digital product includes climate information for rainfall, temperature, soil moisture and evapotranspiration tailored to each commodity’s climate risks. As at the end of June 2024, climate information has been tailored for 22 commodities across cropping, livestock, horticulture, and viticulture. The data is updated approximately annually.

The aim of the My Climate View tool is to improve resilience to climate change in Australian agriculture, by providing better climate information to support longer-term strategic decisions. It is intended to raise awareness of the potential changes due to climate change, and to provide an evidence base to support adaptation and behaviour change. The My Climate View brand was released in 2023, building on earlier prototypes called ‘Climate Services for Agriculture’ and can be accessed at My Climate View.

According to definitions of co-production in Fleming et al. (2023), CSA is co-developed and co-delivered, rather than co-designed, as the original objective (to produce a climate projection tool) did not involve end users. Furthermore, it fits under pragmatic co-production agendas (Jagannathan et al. 2020) to produce and disseminate knowledge, and in

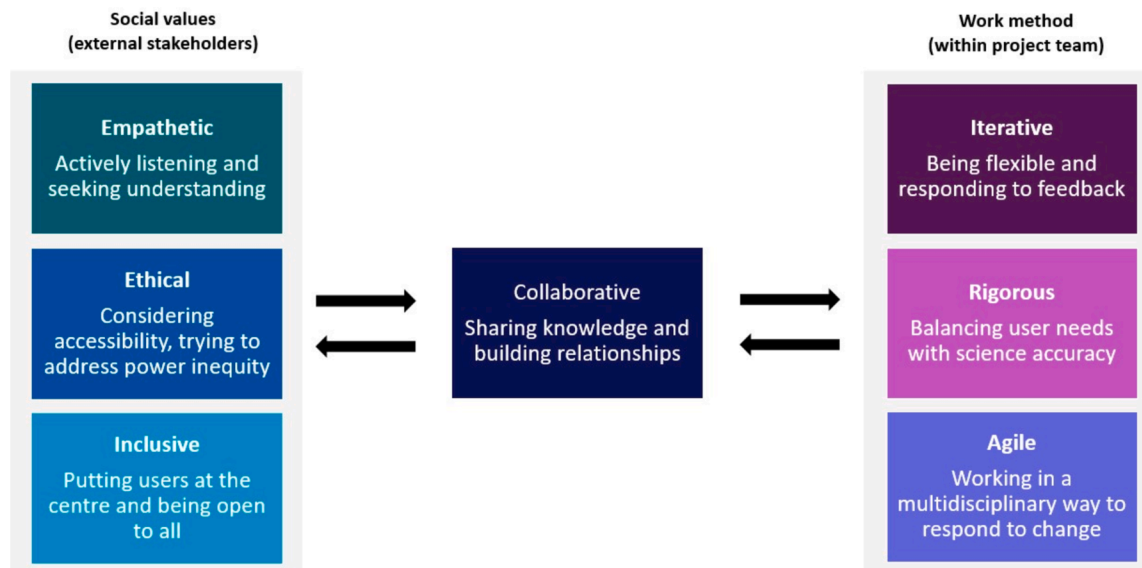
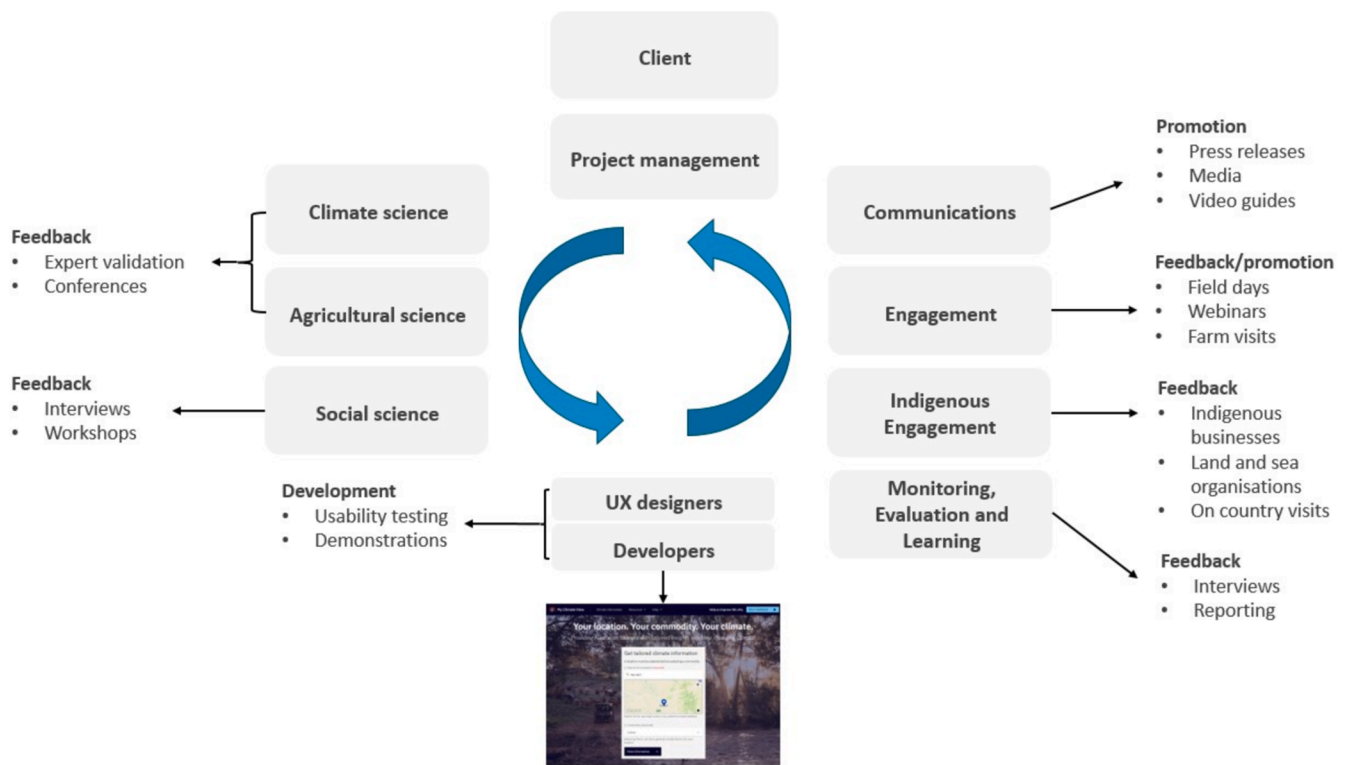
the ‘public service’ lens of co-production (Bremer & Meisch 2017): where government and citizens work together to produce public services. The program development and delivery has been careful to prioritise user needs and feedback and there have been many changes over the four years of the program so far. The most substantial have been to simplify the layout of information presented, consider a broader range of potential users and add more supporting details around how to understand and use projections.

The project team behind My Climate View included approximately 40 people, ranging from researchers in data science, climate science, agricultural science, social science, Indigenous engagement, software engineering, product development, user experience, communications, as well as knowledge brokers, project managers, monitoring and evaluation experts and agricultural consultants, who all had different time commitments that together contributed to My Climate View. The authors of this paper span all these areas of expertise. One author was not part of project team and contributes an outside perspective. Extended research and engagement underpin the development of My Climate View, involving more than 6000 interactions including demonstrations, conference presentations, webinars, field days and training sessions, usability tests, visits with Indigenous land holders on Country, as well as over 100 qualitative interviews with target users (see Fig. 1). Gathering targeted feedback from more than 850 stakeholders, the team has been able to build an understanding of the different climate information needs for Australia’s agricultural sector. The farmers, advisers and land managers were invited to provide input on:

- what climate information is relevant for what they grow, graze, produce or manage
- what climate information is difficult to understand
- how information is presented
- how information is used.

Feedback from stakeholders helped to understand the potential benefits users get from the tool. These are quite diverse, but examples include: testing potential management decisions, such as purchasing a new property, or planting a new crop, building large scale infrastructure, or planning adaptation (irrigation, agistment, selling down stock, pesticide management and many others).

From this research and engagement, we have distilled best practice principles that we used to guide our climate service development, illustrated in Fig. 2 (below). These principles are: Empathetic, Ethical, Inclusive, Iterative, Collaborative, Rigorous and Agile. The Empathetic, Ethical and Inclusive principles describe social values of power, user needs and knowledge and draw from discussions of the co-production of climate services literature described above. The Iterative, Collaborative, Rigorous and Agile principles discuss the technical process of climate service development and output and relate to literature around technology development and innovation. These principles are not intended to be exclusive and do not show a linear progression, as they often occurred simultaneously, or in different combinations and to different extents throughout the development of My Climate View. We found them useful to help us to reflect on our processes and to identify areas of opportunity and further challenge. We elaborate on the key lessons that underpin these principles below, describing examples from our case, which we hope will help others embarking on climate service development for users at any scale. This work, and the principles we describe, align with other efforts underway calling for climate services which are more iterative, user-centred, agile and outcome focussed, in Australia (DCCEE 2023b), in Europe (Del Poro et al., 2024) and globally (Boon et al., 2024).



During the many engagements the CSA team conducted, climate

literacy and climate scepticism posed a challenge. Educating the public about climate information and engaging with users despite climate scepticism are a key gap for enabling climate information to be useful and used and were part of the vital work conducted by CSA's engagement team. However, 'debating' climate change with sceptics, or educating users about climate scenarios, climate models and interpretations of accuracy and uncertainty sometimes required different capabilities and materials than the engagement team had at hand and developing materials for this purpose was beyond the scope of the CSA impact pathway. Nevertheless, the engagement team found that their discussions could still focus on management decisions, regardless of perceptions of the causes of climate change.

Scope limitations affect all climate service development. No singular climate service offering can be expected to simultaneously raise climate literacy, counter climate misinformation, reverse climate scepticism and support contextual decision making. Therefore, credibility, salience and legitimacy are important factors in understanding how climate information will be interpreted by users (Cash et al. 2003). Empathy is also crucial as a starting point in discussions with users about their diverse situations.

## Ethical

### *Prioritising public good*

The ethical principal is about the motivation for the work and the vision for what will be achieved. CSA is publicly funded and not for profit and thus a strong motivation for its development was to achieve a tangible public good outcome, namely, improved resilience to climate change in Australian agriculture. However, our experience quickly surfaced some tensions in achieving this in practice. Climate data are valuable, but also complex and uncertain. When brought together with economic, social and Indigenous knowledges and other environmental information, it can lead to the potential exacerbation of unequal power dynamics around who has access to information and insights. National scale, publicly funded climate services arguably have an obligation to prioritise inclusion, justice and diversity – allowing different cohorts of users to be empowered (Snow et al. 2024). Aiming for broad accessibility, including users who require specialised approaches, like Indigenous land managers, and non 'target' users, such as researchers, students or general citizens. In our case, we found that more visual versions of the tool featuring interactive maps were useful for engaging with broad audiences, including Indigenous land managers, because the visual and spatial elements made information more accessible when thinking at a larger scale than paddock boundaries (Jakku et al., in press). Making the tool accessible to different groups in different ways is an important way to address power imbalances.

To achieve visions of improving adaptation outcomes in Australian agriculture, tools need to be co-developed with different audiences (e.g. Jagannathan et al. 2023; Fleming et al. 2023) and there needs to be support for a diverse range of users, and diverse engagement approaches, which takes time. We quickly realised we could not become a 'one stop shop' for national scale climate adaptation, but just one important piece. This is because it is not possible to serve everyone's needs in one tool. Some users want to play with the data themselves, some want to compare the data with their own records, and some want just one clear message. Multiple tools will always be needed to answer different questions in different contexts. Amongst this diversity, sustainable funding models for public good information cannot be solely market driven, especially in establishment phases (Webb et al. 2019). Similarly, while climate information may be made available for entrepreneurs or industries to value-add and on-sell, a key opportunity exists in harnessing multiple industries and multiple regions for a 'bigger-picture' and longer-term national-scale view of adaptation, which would otherwise not be achieved by individual states, industries or individuals working in isolation. This type of national-scale planning, monitoring

and reporting is necessary for global initiatives such as the Sustainable Development Goals and Climate Adaptation Stocktakes. At the global level, explicit consideration of the ethics underpinning political and responsible decision-making are particularly important, including national funding for information services (Webber 2019; Wiarda & Doorn 2023).

Sustainable (ongoing) funding models are a challenge that the CSA team is still grappling with. Currently, work is funded to design, build and raise awareness of the tool, but there is no concrete plan for where, or if, the tool will be supported after the program funding ends. To date, we have found that there are different audiences interested in My Climate View, for different reasons, but most have little willingness or no capacity to pay. To provide this service only to users willing to pay for specialised climate information (such as only large corporate farmers, or agricultural investors) would significantly change the trajectory of the tool's development and potentially increase existing information asymmetries and power disparities. In Australia, general weather information can be accessed for free, but there are many paid for services that package, interpret or value-add to historical weather information, such as Digital Agricultural Services Pty. Ltd. Furthermore, in Australia, there is a growing list of consulting companies such as Deloitte, that charge for climate projection services. If climate services follow a similar trajectory of a mix of free and paid-for services, trust, rigour and equity are important considerations for users which public good entities need to monitor and support (Keele, 2019).

## Inclusive

### *Nationally accessible*

The inclusive principle describes the need to be open-minded in who is involved in co-production of climate services and to consider broad and diverse engagement, but also to be mindful of producing a tool that will be able to be widely used, bringing together both universal design and inclusive innovation literatures (e.g. Snow et al. 2024). Open access to climate service information will allow all users to benefit from the potential opportunities of climate change, not only those investors with the resources, time and capacity to utilise climate information. For nationally funded, public good climate services, inclusivity and accessibility become even more important.

Climate services must be feasibly scoped and better integrated with the wealth of other decision support resources available. How 'data delivery' climate services fit within a larger context of risk assessment advice, decision-support tools, and enablers for uptake (Palutikof et al. 2019), as well as non-climate specific behaviour change support services, education services and advisory services is an on-going area of research, highlighting the need for more end-to-end and integrated planning of projects over the longer term, instead of continually funding new initiatives and tools (Murphy et al. 2023). In CSA's Indigenous engagement, we found there was interest in exploring how to integrate Indigenous seasonal calendars, historical climate observations and climate projections, which could produce useful insights for adaptation. Other ways that CSA aimed to be inclusive included engaging extensively with commodity groups not yet included in tool, and learning how users might use the general climate data or adapt the information from a different commodity for their personal situation. Talking to regional planners and policy makers, we also saw how My Climate View could be useful to make planning decisions about water management or land use, considering climate projections. Being inclusive in our engagement was important for us to understand the potential of the tool, but of course adds to the cost and time taken for engagement, with 'non-target' users.



## Iterative

### *Building flexibility into design*

The iterative principle describes the need to have a flexible mindset that is open to adapting in response to user feedback, as well as changes in situation, team personnel, funding, and learning. Software development that enables processes for updates, or adding or changing components over time without having to wholly change underlying software is increasingly important for climate services. In CSA, design changes can happen independently from data restructures because the data storage and management are separate processes to the user interface, allowing more flexibility. Software architecture where data, data pipeline, application program interfaces (APIs) and front-end design are independent allows more rapid updates and ability to respond to user feedback. This requires new ways of investing in long-term structure and provision of core back-end data that can be shared and improved collectively. Given there has been a proliferation of data portals relating to different components of weather and climate information, there has also been duplication of effort and some confusion amongst users about the differences between institutional offerings and products (Vaughan and Dessai, 2014; Webb et al. 2019).

In the lifetime of My Climate View, there were many iterations of ways to present the climate data as we developed (and iterated) use cases, responded to feedback about how information was being received, and what was most important. These will need to continue into the future as new climate information is produced. Additionally, new analyses of hazards or other discrete climate factors are always being developed, as well as different information at different resolutions and scales, and this is likely to become more prominent as climate impacts worsen (Gitonga et al. 2020). How, or even if, new sources of information can be integrated into an existing national tool requires careful thought and building flexibility and longevity in software architecture, software development capabilities, access and intellectual property rights, as well as how guides are updated and so on. Developing well designed software architecture both from a back-end data and data pipeline perspective as well as from a front-end design perspective is critical to ensuring longevity, scalability, and sustainability of systems. In getting to this goal however it is expected that such systems will need to evolve before they become more stable and sustainable architectures (both front and back-end systems) that can be reused and updated relatively easily.

## Collaborative

### *A co-production mindset*

The collaborative principle aims to capture the importance of working together, both internally as a project team, and externally with users. A collaborative mindset, open to co-producing all aspects of the work, was a core way of working in CSA. This required support from all members (including the funder and the project managers) to be flexible to change ways of working to respond to feedback and changes in direction, both from internal discussions and from external engagement. CSA reorganised internal structures to build working groups and share communication efficiently, as required, and different groups collaborated at different times in different ways, for example, agricultural and climate scientists might be brought into field days as required, or developers might sit in on usability testing of new product ideas.

The CSA team included a small number of climate and agricultural scientists, who at times had to navigate a tension between improving the science information and supporting users' or other team members understanding of the science. In other words: balancing user needs for detail with scientific rigour about accuracy was an important aspect to the design and delivery of the project and there were many debates about the right type of caveats to include, the right presentation metrics

(e.g. averages or ranges), level of detail to provide, and how to explain terms like uncertainty. Similarly, other disciplines involved in the team also had to manage their own work, as well as spending time helping others in the team to understand the work they were doing. This demonstrates how interdisciplinary programmes of work need to invest time into building social learning and social capital in the team, to achieve innovative and impactful outcomes (Carr et al. 2018). Bringing teams of scientists together requires its own science in interdisciplinary approaches and transdisciplinary (when it includes non-scientists) methods, in addition to the work conducted within the scientific disciplines involved (Burch et al. 2023). Funders and researchers may need to challenge assumptions about scientific roles and expertise when communicating, convening, collaborating and training which can all form part of a climate science role (Owen and Ferguson, 2019).

In the case of CSA, delivering a live prototype early was helpful for the team to gather feedback and clarify our purpose. It meant time was not wasted trying to build a 'perfect' tool. But the downside is that decisions that are made early, without substantive stakeholder input, have lasting legacies on objectives, scope and framing (Fleming et al. 2023). This resonates with the experience reported by Golding et al. (2024) who noted that early engagement sometimes leads to difficulty deciding on the most effective path, as there are many diverse needs, and it takes time to establish priorities and manage expectations. Starting prototyping early allows time for updates and changes in response to feedback but there are inevitably users who get attached to certain features or spend time learning a tool that then changes. For some CSA users there was frustration or confusion when aspects of the tool changed, but the team generally navigated changes by adhering to the vision of benefiting the many, rather than the few.

## Rigorous

### *Challenges measuring change*

The rigorous principle captures the importance of scientific integrity as an underpinning foundation of the development of CSA. In trying to respond to user feedback, data accuracy and our responsibility to provide good information were paramount. In addition, in trying to respond to client requests for evaluation 'metrics' of adoption and impact it was important that we capture credible evidence of our work. Attribution of change in complex systems is widely recognised to be a wicked problem, as a 'problem that almost seems to avoid resolution and/or that attempting to solve it keeps generating hosts of other and seemingly unrelated problems' (Andersson & Törnberg 2018, p.119). This is further the case when innovation in social systems is involved. Available quantitative metrics such as website hits do not capture usability factors or outcomes such as adoption or adaptations. For example, while using Google analytics, we can determine that My Climate View has had more than 20,000 unique visitors, yet we cannot determine who these visitors are, or whether the tool changes their thinking or behaviour. New approaches are needed to monitor how awareness and behaviour change scale out, indirectly, through different audiences. Evaluation of climate services needs to be based on impact pathways (Tall et al. 2018). In addition, ways of capturing how the tool is used successfully, or not, in real life contexts (as opposed to with a formal introduction or member of the project team on hand to answer questions) are needed to improve the tool. These types of impact pathways that involve use of the tool 'without us' are difficult to capture, and difficult to assess, as no-one makes decisions on climate information immediately or alone, so causal links between data and decisions are always blurred. User-centred evaluative frameworks such as Google's HEART framework and goals-signals-metrics process (Rodden et al. 2010) offer one potential pathway to better align program objectives with bespoke measures of success, which consider longer time frames and both quantitative and qualitative measures, but these processes are still evolving. Evaluation rubrics, and models of change across scales are an

important area for further exploration (Visman et al. 2022). Our experience working in CSA demonstrated that we need new ways of thinking about how innovation and systemic change is monitored and evaluated, especially when projects are large and transdisciplinary. Human-centred design is still a new approach in large inter- and transdisciplinary projects (Yan et al. 2021) supporting a shift of focus from the final product to the behaviour change process (Daniels et al. 2020). These approaches involve different types of science and more collaborative methods of developing ideas (Larosa & Mysiak 2019; Fleming et al. 2023). As climate services move towards more transdisciplinary knowledge production processes (Bojovic et al., 2021) involving more non-scientists as part of innovation cycles, strategies for sharing power and decision making more equitably, funding arrangements, and the required skill-sets of individuals will likely need to change (Fielke et al. 2023).

## Agile

### *Adapting ways of working*

Building on agile project management philosophy,<sup>1</sup> the agile principle describes how both a flexible mindset and flexible processes were required, both within our team, but also with government and industry partners. To respond to user feedback and build My Climate View iteratively required a project management approach that was agile and could bring different groups together to work on different components of the tool at different times. An example included the plan, conduct and review of changes to the front-end interface, such as how confidence in rainfall was represented. Challenging assumptions about science processes, policy processes and decision-making processes underpins system change, because science and policy are also part of the systems which need to become more agile, flexible and reflective. Achieving system change is hard in pragmatic, government funded approaches, but reflexivity and an agile approach can start to shift power structures that might otherwise hinder innovation (Bremer & Meisch 2017; Jagannathan et al. 2020).

Climate data are continually being updated and repackaged, sometimes with only incremental additional value in terms of the interpretations of the data (Grose et al. 2020) because users often hold assumptions that 'new' data are better. There is a seemingly insatiable appetite for more accurate or certain data, which can never be satisfied because the future can never be predicted with absolute certainty, meaning expectations need to be managed (Golding et al. 2024; Haines 2019). Instead, the conversation needs to shift to what data are most plausible, relevant and actionable (Werners et al. 2021). Even if perfect data and models existed, climate projection decisions would still be limited by the reality that climate information is part of a broader suite of inputs that influence decisions, and decision making is often distributed and socially mediated. Therefore, science and policy experts should collaborate with end users to identify the most relevant data for specific outcomes, as well as how to present it in accessible, understandable ways, to align with existing decision frameworks (Bruno Soares et al. 2018), and collectively navigate the entire process from information gathering to implementation (Palutikof et al. 2019).

### *Lessons learned*

Empathetic, Ethical, Inclusive, Iterative, Collaborative, Rigorous and Agile principles describe the themes of our lessons learned, which include many overlaps and interconnections. As part of being iterative, inclusive and collaborative, CSA tried hard to respond to user needs, but it was difficult to suit everyone. CSA could have better prepared users for changes to the tool, making changes incrementally where possible and offering 'opt-ins' to some changes. Many of the users we spoke to

expressed a desire for different 'versions' of the tool, with (or without) complex data, for example. Decision support tools could consider separate interfaces that target basic, intermediate and advanced levels of technical capability. Examples of this which provide guidance material, case studies and training, include Climate Change in Australia<sup>2</sup> and CoastAdapt.<sup>3</sup> However, producing multiple versions of tools to suit a range of users often increases maintenance cost and long-term technical debt, especially if tools continue to be updated over time.

The CSA program team worked hard to be agile, and there was a lot of 'learning while doing' in our organisation of team structures and management processes. For any long-term project or enduring product, there will be staff turnover. When new staff join there is time spent going over old ground. We found decision registers are one way to get people up to speed quickly, but there is always a loss of knowledge, and changes in direction (sometimes for the better) with new staff members, ideas and experience. Innovation requires a balance of new ideas and enough social cohesion in the team to enable good communication, overcome challenges and harness team members' passions and skills (Carr et al. 2018). Maintaining cohesion in the team through a strong vision and a supportive culture (including these principles) were helpful to maintain momentum.

In the process of being iterative and rigorous, an area where new research questions emerged, and which we realise are not yet well examined in the context of CSA, was in the potential role of AI as an assistant in supporting new users' interactions with climate services. For example, Large Language Models (LLMs) trained with chat functionality combined with appropriate literature may play a fundamental role in answering initial user queries and suggesting actions (Vaghefi et al. 2023). LLMs can be crucial where soft introductions by scientists or advisors at scale is not practical due to resourcing constraints, the emotional burden of communication (Head and Harada, 2017) or exponential growth of climate literature (Callaghan et al. 2020). Artificial Intelligence could speed and scale the synthesis of data and expand understanding of climate change, however it also poses risks, potentially exacerbates social and ethical inequalities and can itself be a significant source of climate emissions (Cows et al. 2021). How AI fits with the principles that we discuss here is an area that we intend to explore in the future.

Finally, another overlap between many of the principles is the challenge in measuring and evaluating the success of qualitative and subjective principles like empathy, collaboration and inclusion. Ultimately, whether CSA will be enduring remains to be seen. According to Golding et al. (2024), new measures of success should recognise the importance of relational, embodied learning, connection, knowledge sharing, fun and trust. This is additional to and alongside more traditional outputs, such as peer-reviewed papers and tangible products. The CSA program still has some way to go, but defining the end dates for development, for funding and for engagement, are tricky questions. Especially seeing as so much of the work in applying climate projection information is iterative, dynamic and will occur gradually over time (Lu et al., 2022). Nevertheless, even products that are relatively stable need to move from research heavy phases of development to user-testing, iterative improvement and become operational applications. Clearly determined performance indicators are needed at all stages, as well as a clear vision of when 'success' has been achieved. Monitoring, evaluation and learning is critical.

These principles emerged from our reflections on developing CSA, but we note that they extend beyond our team and our project. Around the world there is currently a real opportunity to develop scalable climate services, that are focused on users and decision-making. Underpinning this is transdisciplinary science that needs to be developed carefully, given issues of trust and transparency, uncertainty and

<sup>1</sup> <https://www.atlassian.com/agile/scrum/agile-vs-scrum>.

<sup>2</sup> <https://climatechangeinaustralia.gov.au>.

<sup>3</sup> <https://coastadapt.com.au>.

responsibility (Jakku et al. 2019; Wiseman & Sanderson 2017). However, it is not just a scientific endeavour, policy innovation is also required to better evaluate and support scaling out through different networks (Andersson & Törnberg 2018; Jagannathan et al. 2023). Our experience highlighted the importance of real time, objective monitoring, evaluation and learning (MEL) conducted as part of the project that allowed fearless feedback to be provided by and to the project team, funder, users and others, and responded to quickly.

## Conclusion

This paper reflects on the experience of a multidisciplinary team working to develop My Climate View in Australia. Our experiences highlight the need to think carefully about how large programs of work are funded and organised. We see potential in further co-development with diverse users, integration with existing services, development of methods for evaluation and commitments to public good research. We recognise that climate services are integral, but insufficient, to achieving climate adaptation and we hope to see more of a focus on building on the lessons we have learnt to rapidly progress climate actions. Our experience highlighted seven principles that guided our work: Empathetic, Ethical, Inclusive, Iterative, Collaborative, Rigorous and Agile. We hope that consideration of these principles in other climate service and broader technological development processes will improve the outcomes and ultimate impacts achieved.

Our work highlights gaps in current research, including methods of evaluation of the development of national transdisciplinary programs of work, and the social outcomes achieved, as well as evaluation of climate projection tools. In addition, research areas which require more attention include examples of longer-term climate adaptation, examples of climate projections being used in practice, how AI might be used responsibly in this space, and more end-to-end examples of climate information development through to use. These are important areas of research if we are to successfully respond to climate change challenges and opportunities.

## CRedit authorship contribution statement

**Aysha Fleming:** Writing – original draft, Conceptualization. **Simon Fielke:** Writing – review & editing. **Emma Jakku:** Writing – review & editing. **Yuwan Malakar:** Writing – review & editing. **Stephen Snow:** Writing – review & editing. **Sarah Clarry:** Writing – review & editing. **Carly Tozer:** Writing – review & editing. **Rebecca Darbyshire:** Writing – review & editing. **Duncan Legge:** Writing – review & editing. **Amy Samson:** Writing – review & editing. **Mahesh Prakash:** Writing – review & editing, Funding acquisition. **Tammy Hunter:** Writing – review & editing. **Vincent Nguyen:** Writing – review & editing. **Karen Wealands:** Writing – review & editing. **Stephanie Dickson:** Writing – review & editing. **Kevin Hennessy:** Writing – review & editing. **Graham Bonnett:** Writing – review & editing, Funding acquisition.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: All of the authors, except for Kevin Hennessy, declare they have received funding from the Australian Government, Department of Agriculture, Fisheries and Forestry.

## Data availability

No data was used for the research described in the article.

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