nature climate change

Article

https://doi.org/10.1038/s41558-024-02021-2

Multi-decadal climate services help farmers assess and manage future risks

Received: 19 October 2023

Accepted: 24 April 2024

Published online: 21 May 2024

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Climate services can support on-farm decisions, yet this potential is currently not fully realized. Here, using a participatory qualitative risk analysis framework, we introduced 24 Australian farmers to My Climate View, an Australian online, multi-decadal climate service, and asked them to identify, assess and discuss management of long-term risks in light of its projections. We found that multi-decadal projections can help farmers to better understand future climate risks, potentially reducing the psychological distance of climate change. The use of long-term climate projections, however, can be impeded by lack of confidence in data, so leveraging the expertise of trusted service providers may help boost farmers' confidence. Finally, though climate services providing multi-decadal projections can help farmers to identify future climate risks, they require interactive and recurring engagement to turn awareness into action.

In 2009, the Global Framework for Climate Services was established to address climate risks through cohesive implementation of better 'climate services'[1], leading to an increase in climate services development. Climate services is a collective term for the generation and provision of climate information tailored to user decision-making needs[2]. However, despite initial promise, questions remain about climate services' direct benefits to society[3,4]. Key challenges include a lack of equitable access to climate services, and inadequate interactions between users and climate service providers[5]. Three key tensions hinder the successful rollout of climate services: (1) a focus more on producing climate service products rather than understanding processes of use or pathways to impact; (2) the development of climate services based on assumed demand rather than directly responding to user preferences; and (3) economic evaluation of climate services rather than real-world outcomes. In this Article, we empirically explore these challenges from the perspectives of potential users of climate services.

The scope of climate services is broad. Here, we focus on multi-decadal climate projections (20+ years) in the future (also referred to as long-term projections in the subsequent sections). We also focus on applications in agriculture, one of the five priority areas for climate services identified by the Global Framework for Climate Services[6].

Globally, the agriculture sector is facing serious consequences of climate change requiring both adaptation and mitigation[7,8], and nations are increasingly investing in climate services targeting farmers[9,10]. Studies have explored farmers' risk perceptions and their use of climate services, including short-term weather (1–14 days) and seasonal forecasts (3–6 months)[11,12]. However, there is limited literature demonstrating how the agricultural sector uses multi-decadal projections to manage long-term risk[3,13]. Hence, the utility of multi-decadal climate projections in farming is far less obvious than near-term climate information[3]. We attempt to address this gap with the research question 'how would multi-decadal projections affect farmers' risk management decisions pertaining to future climate risks?'. We use an Australian case study of the climate service, My Climate View (MyCV), and conduct 24 qualitative, semi-structured interviews with farmers from different geographic locations and across multiple commodities.

Australian farmers are already responding to climate variability and extreme events, such as bushfires, floods and droughts[14,15]. Climate services providing climate projections to Australian farmers are increasingly becoming available (Supplementary Note 1). The Australian Government through the Future Drought Fund is investing $29 million in the Climate Services for Agriculture (CSA) programme from 2020–2024, jointly implemented by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology[16]. MyCV, a product of the CSA programme, is a national-scale service that provides local,

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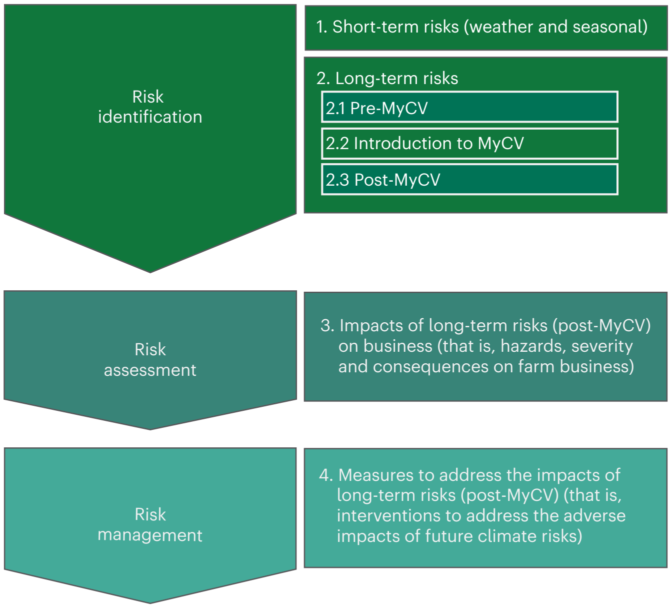

Fig. 1 | Participatory risk analysis framework used in the study. The framework follows four steps: (1) Identification of short-term risks including risks currently experienced, such as extreme daily and multi-day rainfall, frosts and very wet or dry seasons. (2) Identification of long-term future climate risks (20+ years), either before (2.1) or after (2.3) the introduction of MyCV (2.2). Through this process, we discussed the changes in risk perceptions pre- and post-MyCV, which was a critical step to understand the role of MyCV in informing long-term decisions. (3) Risk assessment involved in identifying the impacts future climate risks (post-MyCV) might have on agriculture. This included participants assessing hazards, severity and consequences on their farm business[45]. (4) Risk management involved in identifying strategies to reduce the impacts of future climate risks (post-MyCV). Participants were asked what they would do differently to manage future risks that came to light from the MyCV projections. Participants in this step identify interventions to address the adverse impacts of risks through proactive planning and engagement[46].

agriculturally relevant historical climate data and future climate projections for the 2030s, 2050s and 2070s in one tool (see Supplementary Note 2 for further details). Other Australian climate service products currently available are specific to either a single location or a commodity group.

Barriers exist to using multi-decadal projections informing on-farm decisions, including (1) limited availability to agricultural sector-specific needs[3], (2) limited relevance to farmers' focus on shorter-term decision horizons[17,18] and (3) the 'psychological distance' of connecting large global changes with individual experience of the present[19]. The concept of psychological distance, noted as a barrier to climate change action[20,21], contends that individuals only experience here and now, with themselves at the centre, and any other experience with other objects and people occurs at mentally constructed distance[22]. To link climate change more directly with the here and now, this paper aims to explore whether climate services with localized and commodity-specific multi-decadal climate projections can assist farmers to identify future climate risks and make decisions to manage those risks. This makes MyCV an ideal case study.

To address this, we developed a participatory qualitative risk analysis framework (Fig. 1), inspired by the concept of action research—a method that allows the examination of an issue as well as the identification of solutions in a participatory way[23]. This qualitative approach allows deeper engagement with participants to facilitate understanding of risk perceptions and management decision-making. The framework consists of three major components of risk analysis: risk identification, risk assessment and risk management[24,25]. We used this framework to engage research participants in four steps to identify, assess and discuss management of future climate risks in a participatory way (Fig. 1).

Table 1 | Risk categories and their descriptions

Risk category	Description
Known risk	■ Risk is familiar. ■ Exact hazard(s) and consequences have been identified. ■ The likelihood of the risk occurring is known.
Uncertain risk	■ Risk is familiar. ■ Exact hazard(s) are identified, but consequences are vague. ■ The likelihood of the risk occurring is highly uncertain.
Ambiguous risk	■ Multiple hazards in combination have been identified. ■ The likelihood of the risks occurring is highly uncertain. ■ Consequences of the risks are vague. ■ The scales of hazards are unknown.
Unknown risk	■ Risk that cannot be identified. ■ Unidentified hazards, likelihood and consequences.

Risk identification

Participants detailed risks associated with weather and climate hazards across short-term and long-term timescales, which were categorized into four groups based on the order of complexity associated with their consequences, likelihood and scale (Table 1). Our analysis of risk draws from ref. 26.

The risks identified by the participants across the two timescales have a varying level of complexities (Fig. 2). Two types of risk, known and uncertain, were identified in the short term. Most participants knew existing hazards and the resulting consequences to their farm. Various hazards were discussed, such as variations in winter chilling requirements, fungal diseases caused by humidity, and lack of rainfall, and their effects on the yield. For instance, a broadacre cropping farmer described a short-term risk, which we classified as known risk, as, "... lack of rainfall is obviously the bigger issue...the wet season finishing too early...the effect on...cutting an irrigation crop off a bit early. It just means reduced yield" [F18]. Participants also identified uncertain risks, which were mainly linked with hazards that were sudden-onset and extreme events, such as hail, extreme heat and extreme rain. For example, one mixed cropping–livestock farmer described the effects of extreme rain and heat events, which we classified as an uncertain risk: "if you get too much water in winter, it [field] can get waterlogged...if it dries up in spring, it [crop] won't flower that much...if it's raining too much in December like it tends to these days...that can affect getting the crop harvested..." [F14].

The perceived complexity of the long-term risks pre-demonstration of MyCV (pre-MyCV) was greater than that of the short-term risks. It included all categories of risks, ambiguous risks to the most extent and uncertain risks to a lesser extent. Participants who were more certain about future climate risks mostly spoke about the climate getting drier and hotter. Some also stated that the climate was going to remain unchanged. Only two farmers identified risks that were categorized as uncertain. In relation to ambiguous risks, participants described perceived trends in climate change as a combination of hazards with uncertain scale and consequences. A cropping and livestock farmer said, "... volatile probably. I suppose more extreme. So, more hot spells, more heavy torrential rain hence less consistency in weather" [F17]. Additionally, participants considered climate change a psychologically distant phenomenon and hence described that future risks are unknown, as one livestock farmer stated, "I actually don't know. I think...the changes [in climate] are over such a long period of time that I don't think I would personally notice much of a change in 20 years" [F20].

After the MyCV demonstration (post-MyCV), the range of future climate risks narrowed to two categories, as opposed to the four

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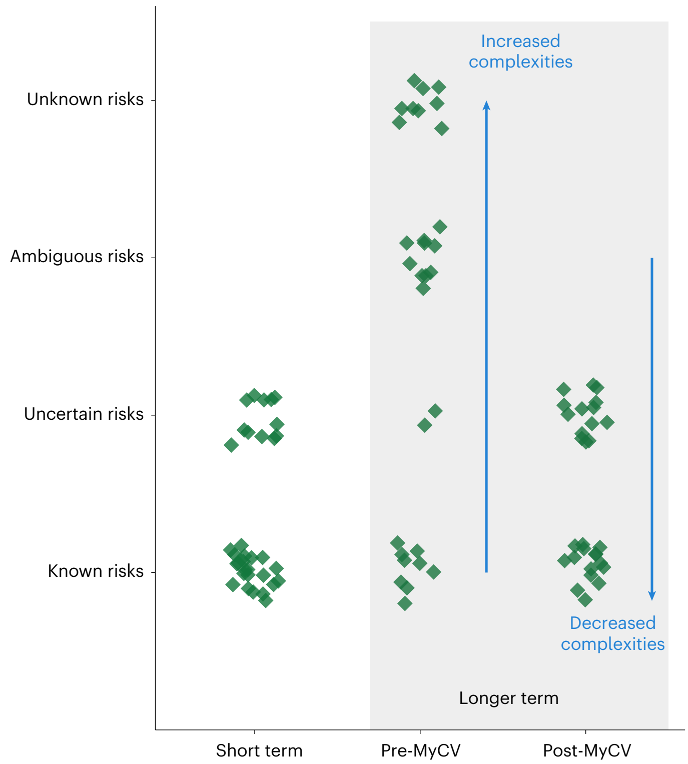

Fig. 2 | Distribution of risks across two timescales. The unshaded area shows short-term risks, and the shaded area shows long-term risks pre- and post-MyCV. For the short term, risks were categorized mainly into known and uncertain risks. In the long term, risks pre-MyCV were mostly identified as either ambiguous or unknown, followed by known, and only a few identified uncertain risks. Thus, participants perceived long-term climate risks as more complex than current risks. The range of risks post-MyCV was narrower than pre-MyCV and were categorized into only two types of risk: known and uncertain. This indicated that the climate information provided by MyCV helped participants to reduce their perceived complexities of future risks. The data points within the risk categories indicates individual participants identifying risks belonging to the risk category. Participants were allowed to identify multiple risk types across both timescales. Our analysis explored whether these risk categories would vary across business, climatic zones and commodities (Supplementary Note 3).

pre-MyCV. Most identified known risks, followed by uncertain risks. One viticulturist explained a decreasing frost risk and said, "...there will be less frost risk because some of the heat-resilient varieties actually start growing from winter sooner...So, hedging our bets on the frost risk decreasing" [F22]. Participants also spoke about risks with a high level of uncertainty. For example, while referring to the decreasing rainfall trend in the projections, another viticulturist said, "...just being aware of the impact it may have on aquifer recharge...will the water be available if there isn't the recharge over a long time and our water allocations are cut. How's that going to look in terms of that early season period?" [F19]. Participants being able to identify specific future climate risks to their business post-MyCV can potentially be seen as an example of a reduced psychological distance to climate change and action.

Risk assessment

The risk assessment phase only involved assessing the impacts of long-term risks post-MyCV (both known and uncertain combined). Five themes were identified, on the basis of participants' assessment of risks, which depicted the strategic assessment of impacts rather than the short-term business operation (Fig. 3).

Participants shared their opinions about their confidence in the data, diverging in some cases. Some thought that making such climate information available for farmers was good, but they expressed some scepticism. One viticulturist explained, "you've got to take it [projections] with a grain of salt, but it's better than no information" [F19]. Participants also questioned the accuracy of multi-decadal projections. Other participants showed confidence in the projections and gave two reasons why. First, trust in the service provider was identified as critical, as one farmer clarified, "I wouldn't have a problem with trusting that information...I trust the Bureau of Meteorology" [F4]. Second, participant's confidence seemed to be high if the projections match their perceptions, explained by one farmer, "I have to say 100% yes, because my instinct[s] were telling me what we've seen on the data" [F15].

All participants engaged in assessing the impacts on their business. Most discussed the impacts on their commodities; some found no impacts while some saw negative effects due to change in future climate parameters. One livestock farmer expressed, "that's worrying, like how many stock are going to die if we get five days above 40 degrees" [F14]. Another farmer, at a different location, found the projections of annual hot days were not too concerning, as they said, "it's really still not going to worry us. I think when you get above 35 °C is when you might have some issues, but the fact that we can't even get over 30 gives us the confidence..." [F16]. This demonstrates that the same climate projections could have vastly different impacts on business depending on the scale of change, risk tolerance and individual perceptions.

Participants assessed their existing capacity to deal with long-term risks identified post-MyCV; some believed they have adequate capacity to manage the risks, while others reflected on needing additional measures going forward. For instance, one mixed cropping–livestock farmer said, "I don't think there's much more we could do to plan for that increase in heat. We've done what we can already" [F11]. Another farmer explained not having capacity to install irrigation in response to projections of decreased rainfall because they "are not on a natural waterway and have to pump from eight kilometres away to fill the big dam" [F13].

Participants assessed the suitability of their location for their current operation in the future. When asked what the projections would mean for them, one participant said, "I'd think that that chart would tell me that I'm in the right area [for my crop]" [F5]. Some compared different locations to find how other regions that grow the same crop

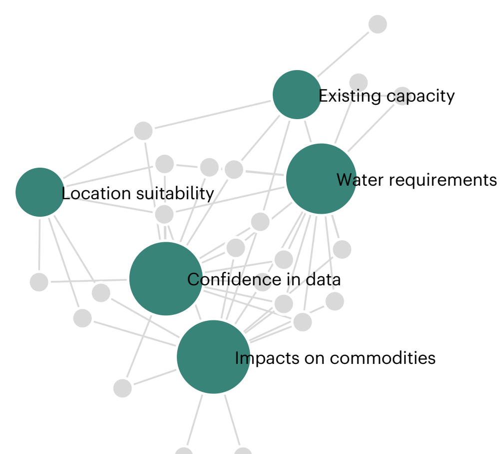

Fig. 3 | Risk assessment subthemes showing how participants anticipated future risks might affect their business post-MyCV. The coloured circles represent risk assessment subthemes; the size indicates the frequency of these subthemes being discussed by participants (↑ size of circle means ↑ frequency). The grey circles represent individual participants. The links show individual participants identifying a subtheme or subthemes. MyCV prompted participants to think about their business in the future and their commodities under future scenarios. We also examined whether these risk assessment themes would vary across businesses, climatic zones and commodities (Supplementary Note 4).

might be affected, as one apple farmer said, "I'd be interested in going to have a look at this [My Climate View] to see what it's going to do to other farms…compared to what mine is going to be like. That'd make me think about business decisions going on in the future" [F8].

Water requirements for their business, for example, sources of irrigation, water allocations, filling existing dams and ways to irrigate crops, were frequently discussed. One farmer questioned, "If it is going to be dry, then where do we source our water from?" [F1]. Another farmer further added, "…because of the increasing heat, I now have to have two forms of irrigation" [F12]. Some expressed their confidence in their existing irrigation sources, as one said, "we've got more water than we need at the moment, so hopefully that [less rainfall] won't be so much of an issue" [F17].

Risk management

Participants discussed various approaches to managing long-term risks (both known and uncertain combined), informed by MyCV, which we grouped into five themes (Fig. 4). They identified changes to their farming practices and their commodities to stay in business by, for example, efficiently managing irrigation, retaining soil moisture, altering fruit harvesting time and adjusting livestock numbers. For example, one viticulturist said, "maintain irrigation systems…I'm definitely looking at [making] changes to our canopy management. Similarly, looking at soil health, so using composts and mulches to better utilise the moisture…" [F19]. Some participants expressed considering changing their commodities altogether. For instance, an avocado farmer observed that "We've done avocadoes for 40 years, and I think we do it pretty well, but if it gets to the stage where you can't grow avocadoes, you've got to look at something else" [F12]. This farmer emphasized the complexity with a perennial crop because they require long-term planning, "…the trouble with a perennial crop like avocado is that you can't say one year I've got avocadoes and the next I'm going to do something else. It's a long timeframe…if you looked at that [projections] maybe you should come up with a 10-year plan to work on something else" [F12].

Participants also discussed options for managing future business investments. One participant explained that they would discuss the projected risks in their board meeting "just so they can actually put that in the back of their minds for any of their long-term planning" [F10]. Similarly, another participant said, "…if you tell me the temperature is going to keep up and the rainfall is not, then I am already at the edge with everything that I have to consider not investing up here" [F15]. Future investments also included purchasing new machinery and building new infrastructure to manage future risks, such as adding overhead sprinklers, building new sheds for livestock to provide shade during extreme heat, and establishing more dams. For example, as rainfall declines were apparent in the projections, one farmer said, "…we need to look more at purchasing more water or establishing more dams…" [F9].

Participants also spoke about continuing their existing practices in the future for two reasons. First, if they did not identify new risks. One viticulturalist who was trialling heat-resilient grape varieties said, "it [the projection] tells me we're probably doing the right thing looking for heat-tolerant varieties" [F22]. Additionally, some participants did not identify any risk management activities for those risks that they already have resources to address. For example, some were less worried about increasing temperature because they already have a reliable water supply. Second, participants who expressed low confidence in the projections were not entirely sure how to act on them. One sugarcane farmer said, "there's probably not a lot of decision-making I can make on any of this climate data…we've just got to harvest when we can, and we stop when we can't" [F5].

Discussion

Our work has three major findings. First, our research suggests that MyCV can help farmers better understand future climate risks, through reducing complexity and potentially reducing psychological distance. This finding helps to contribute to the lack of empirical evidence about how multi-decadal projections can be operationalized in farm decisions[27,28]. The comparison between future climate risks pre- and post-MyCV was valuable to show the changes in risk perception after participants were introduced to contextualized climate information, which helped reduce their perceived complexities of future climate risks, that is, from ambiguous and unknown risks to known and uncertain risks. The pre-MyCV exercise provided a baseline to compare post-MyCV risk perceptions. This guided process helped participants to discuss the implications of climate projections for their commodity and region and use this information to assess the risks on their business and identify risk management plans, in terms of strategic rather than operational decisions[18]. Further, existing literature posits that localizing (and contextualizing) climate impacts can decrease psychological distance[29,30]. MyCV offers location-based and commodity-specific climate projections, which, we argue, played a vital role for participants to understand and identify some specific future climate risks to their business.

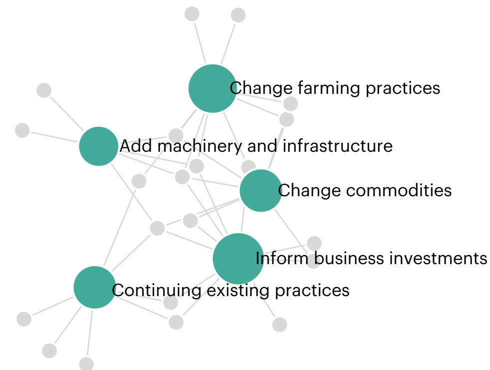

Fig. 4 | Risk management subthemes showing measures to address the impacts of risks identified on the basis of MyCV. The coloured circles represent risk management subthemes; the size indicates the frequency of these subthemes discussed by participants (↑ size of circle means ↑ frequency). The grey circles represent individual participants. The links show individual participants identifying a subtheme or subthemes, which reflect strategic plans that participants perceived would help them to adapt their business to future climates. Supplementary Note 4 explores whether these risk management themes would vary across businesses, climatic zones and commodities.

Second, we found that confidence in data is an important driver for participants to meaningfully interact with projections and subsequently identify future climate risks and actions to address them. It is not uncommon for farmers to express their scepticism towards climate change projections, and this is often based on their experience in perceptions of inaccurate short-term weather and seasonal forecasts[31]. Our research participants similarly reported their confidence in multi-decadal projections as low because of perceived limited accuracy in short-term forecasts (although we recognize there is no link between the accuracy of forecasts and the reliability of projections, participants evidently felt there to be a connection). Participants' scepticism towards projections may also be a function of climate change scepticism generally[32]. The availability of online long-term climate projections is emerging but new, nonetheless[33]. Farmers are not as familiar with climate projections as they are with weather forecasts. Farmers' planning cycles are generally short and are often more concerned with the here-and-now effects on their farm[18].

All participants engaged in risk assessment and management discussions despite some raising views about low confidence in the data. This exemplifies that farmers' confidence in climate projections can be addressed by providing sufficiently detailed and contextualized information through discussion and using the language and context

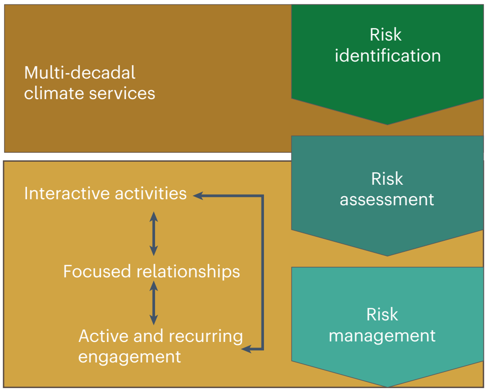

Fig. 5 | A schematic showing the scope of multi-decadal climate services. Climate services on their own are useful for risk identification but require interactive and recurring engagement to be made actionable through assessing and managing future climate risks. Interactive activities help build focused relationships between advisors and farmers, which is a foundation for building trust in institutions and confidence in data for farmers to act on. This systematic discussion of risk identification, assessment and management allowed the conversation to develop in a way that each step relied on the outcome of the previous step. This 'guided discussion' process would benefit from the expertise of professionals working directly with farmers through existing research and extension services, who have additional place-based knowledge and insight into farmers' personal situations[36,47].

they are familiar with. Additionally, participants expressed confidence in MyCV if the projections matched their lived experiences, which suggests that farmers' perceptions should be an active point of discussion and connection for climate services. Our findings suggest that these connections will be important to ensure decision-making based on long-term projections. Participants spoke of their trust in service providers as a driver to establishing confidence in MyCV. Examples of advisors acting in an intermediary role to promote adoption of best agriculture conservation practices are well documented[34,35]. We therefore see value in leveraging the expertise of trusted service providers to boost confidence in multi-decadal climate projections via open discussion and dialogue[36].

Third, climate information that scientists think is useful can be different to what is usable for users[37,38]. Although substantial scientific advancements have been made in the modelling of climate projections, making these digital tools usable requires the adoption of co-production principles in the design of climate services[37,39]. As digital tools, they provide climate information, which could help farmers to identify future climate risks, but turning awareness into action requires guidance and understanding of farmers' specific contexts, which needs deeper and often sustained engagement. This aligns with policy documents and studies that call for building collaborative efforts with farmers to improve their practices[1,40,41]. Moreover, ref. 42 documented that such interactions play a profound role in the utility of long-term projections, particularly to assess and manage future risks, which, we argue, requires interactive and recurring engagement between trusted advisor and farmers (Fig. 5). Previous studies frequently show how it is the combination of relevant information, such as that provided by tailored decision support, with the ability to discuss, explore, test and experiment with different interpretations and management options, that empowers farmers to act[43,44].

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-024-02021-2.

References

1. Hewitt, C., Mason, S. & Walland, D. The Global Framework for Climate Services. *Nat. Clim. Change* **2**, 831–832 (2012).
2. Vaughan, C. & Dessai, S. Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdiscip. Rev. Clim. Change* **5**, 587–603 (2014).
3. Vaughan, C., Dessai, S. & Hewitt, C. Surveying climate services: what can we learn from a bird's-eye view? *Weather Clim. Soc.* **10**, 373–395 (2018).
4. Shannon, H. D. & Motha, R. P. Managing weather and climate risks to agriculture in North America, Central America and the Caribbean. *Weather Clim. Extremes* **10**, 50–56 (2015).
5. Findlater, K. et al. Climate services promise better decisions but mainly focus on better data. *Nat. Clim. Change* **11**, 731–737 (2021).
6. Born, L. et al. A global meta-analysis of climate services and decision-making in agriculture. *Clim. Services* **22**, 100231 (2021).
7. Choquette-Levy, N. et al. Risk transfer policies and climate-induced immobility among smallholder farmers. *Nat. Clim. Change* **11**, 1046–1054 (2021).
8. De Winne, J. & Peersman, G. The adverse consequences of global harvest and weather disruptions on economic activity. *Nat. Clim. Change* **11**, 665–672 (2021).
9. Vaughan, C. et al. Creating an enabling environment for investment in climate services: the case of Uruguay's National Agricultural Information System. *Clim. Services* **8**, 62–71 (2017).
10. Sánchez-García, E. et al. Co-design of sectoral climate services based on seasonal prediction information in the Mediterranean. *Clim. Services* **28**, 100337 (2022).
11. Chiputwa, B. et al. Transforming climate science into usable services: the effectiveness of co-production in promoting uptake of climate information by smallholder farmers in Senegal. *Clim. Services* **20**, 100203 (2020).
12. Hayman, P. et al. Climate change through the farming systems lens: challenges and opportunities for farming in Australia. *Crop Pasture Sci.* **63**, 203–214 (2012).
13. Fleming, A. et al. *Climate Services for Agriculture (CSA) and Drought Resilience Self-Assessment Tool (DR.SAT) Adoption Framework* 1–55 (CSIRO, 2022).
14. Abram, N. J. et al. Connections of climate change and variability to large and extreme forest fires in southeast Australia. *Commun. Earth Environ.* **2**, 8 (2021).
15. Hughes, N., Galeano, D. & Hatfield-Dodds, S. *The Effects of Drought and Climate Variability on Australian Farms* 1–11 (Australian Bureau of Agricultural and Resource Economics and Sciences, 2019).
16. Power, R. et al. A climate resilience platform for agriculture. In *Proceedings of the ISCRAM Asia Pacific Conference 2022* (ed. Huggins, V. L. T. J.) 164–172 (Massey University, 2022).
17. Mase, A. S. & Prokopy, L. S. Unrealized potential: a review of perceptions and use of weather and climate information in agricultural decision making. *Weather Clim. Society* **6**, 47–61 (2014).
18. Robertson, M. & Murray-Prior, R. Five reasons why it is difficult to talk to Australian farmers about the impacts of, and their adaptation to, climate change. *Reg. Environ. Change* **16**, 189–198 (2016).
19. Loy, L. S. & Spence, A. Reducing, and bridging, the psychological distance of climate change. *J. Environ. Psychol.* **67**, 101388 (2020).
20. Wang, S. et al. Construal-level theory and psychological distancing: implications for grand environmental challenges. *One Earth* **4**, 482–486 (2021).
21. Spence, A., Poortinga, W. & Pidgeon, N. in *Risk Analysis* 957–972 (John Wiley & Sons, 2012).
22. Trope, Y. & Liberman, N. Construal-level theory of psychological distance. *Psychol. Rev.* **117**, 440–463 (2010).

23. Burns, D., Harvey, B. & Aragón, A. O. Introduction: action research for development and social change. *IDS Bull.* **43**, 1–7 (2012).
24. Aven, T. et al. in *Society for Risk Analysis Glossary* 1–9 (Society for Risk Analysis, 2018).
25. Renn, O. *Risk Governance: Coping with Uncertainty in a Complex World* (Taylor & Francis, 2008).
26. Bralver, C. N. & Borge, D. in *The Known, the Unknown, and the Unknowable in Financial Risk Management: Measurement and Theory Advancing Practice* (eds Diebold, F. X., Doherty, N. A. & Herring, R. J.) 239–275 (Princeton Univ. Press, 2010).
27. Antwi-Agyei, P., Dougill, A. J. & Abaidoo, R. C. in *Climate Services* 100226 (Elsevier, 2021).
28. Vincent, K. et al. What can climate services learn from theory and practice of co-production? *Clim. Services* **12**, 48–58 (Elsevier, 2018).
29. Chu, H. & Yang, J. Z. in *Risk Analysis* 758–770 (John Wiley & Sons, 2020).
30. Keller, E. et al. A systematic review of the psychological distance of climate change: towards the development of an evidence-based construct. *J. Environ. Psychol.* **81**, 101822 (2022).
31. Griffin, C., Wreford, A. & Cradock-Henry, N. A. 'As a farmer you've just got to learn to cope': understanding dairy farmers' perceptions of climate change and adaptation decisions in the lower South Island of Aotearoa-New Zealand. *J. Rural Stud.* **98**, 147–158 (2023).
32. Grantham, F. R. et al. Building climate change resilience in California through UC Cooperative Extension. *Calif. Agric.* **71**, 197 (2017).
33. Malakar, Y. et al. Comparing established practice for short-term forecasts and emerging use of climate projections to identify opportunities for climate services in Australian agriculture. *Clim. Services* **33**, 100442 (2024).
34. Eanes, F. R. et al. Crop advisers as conservation intermediaries: perceptions and policy implications for relying on nontraditional partners to increase U.S. farmers' adoption of soil and water conservation practices. *Land Use Policy* **81**, 360–370 (2019).
35. Eanes, F. R. et al. Midwestern US farmers perceive crop advisers as conduits of information on agricultural conservation practices. *Environ. Manag.* **60**, 974–988 (2017).
36. George, D. A. et al. Research priorities and best practices for managing climate risk and climate change adaptation in Australian agriculture. *Australas. J. Environ. Manag.* **26**, 6–24 (2019).
37. Prokopy, L. S. et al. Useful to usable: developing usable climate science for agriculture. *Clim. Risk Manag.* **15**, 1–7 (2017).
38. Dainelli, R. et al. Moving climate seasonal forecasts information from useful to usable for early within-season predictions of durum wheat yield. *Clim. Services* **28**, 100324 (2022).
39. Fleming, A. et al. Perceptions of co-design, co-development and co-delivery (Co-3D) as part of the co-production process – Insights for climate services. *Clim. Services* **30**, 100364 (2023).
40. Hewitt, C. D., Stone, R. C. & Tait, A. B. Improving the use of climate information in decision-making. *Nat. Clim. Change* **7**, 614–616 (2017).
41. Lu, J. et al. Explaining the use of online agricultural decision support tools with weather or climate information in the Midwestern United States. *J. Environ. Manag.* **279**, 111758 (2021).
42. Jagannathan, K., Pathak, T. B. & Doll, D. Are long-term climate projections useful for on-farm adaptation decisions?. *Front. Clim.* **4**, 1–15 (2023).
43. Jakku, E. & Thorburn, P. J. A conceptual framework for guiding the participatory development of agricultural decision support systems. *Agric. Syst.* **103**, 675–682 (2010).
44. Ranjan, P. et al. Synthesizing conservation motivations and barriers: what have we learned from qualitative studies of farmers' behaviors in the United States? *Soc. Nat. Resour.* **32**, 1171–1199 (2019).
45. Dawkins, L. C. et al. Assessing climate risk using ensembles: a novel framework for applying and extending open-source climate risk assessment platforms. *Clim. Risk Manag.* **40**, 100510 (2023).
46. Hansen, J. et al. Climate risk management and rural poverty reduction. *Agric. Syst.* **172**, 28–46 (2019).
47. Fielke, S., Taylor, B. & Jakku, E. Digitalisation of agricultural knowledge and advice networks: a state-of-the-art review. *Agric. Syst.* **180**, 102763 (2020).

Methods

The study was designed in line with the participatory risk analysis framework (Fig. 1), underpinned by principles of qualitative 'action research' methodology (sometimes also referred as participatory action research)[48]. Although action research is primarily characterized by its iterative cycles of planning–action–reflection, it is also known as a problem-solving exercise[23]. Action research, according to ref. 23, can be performed in many ways, but building participatory relationships between researcher and participants to critically investigate a problem is an integral element of action research[49]. Additionally, ref. 48 underscores that the value of action research is as much in developing actions as in developing understanding of practices through collaborative learning. This influenced the design of our framework, which is grounded on the participatory understanding of farmers practices and collaboratively building new knowledge on the use of multi-decadal climate projections.

Guided by this participatory risk analysis framework, we employed a qualitative, semi-structured interviewing model to engage with participants and discuss their on-farm risks across two timescales (short term and long term), collectively discuss the projections of MyCV and identify future climate risks, assess their impacts and develop measures to manage those impacts. This approach allowed us to follow an iterative structure as well as engage flexibly and deeply with participants with open-ended questions[50]. The iterative approach was applied to discuss short- and long-term risks and build collective knowledge, but the implementation of the identified risk management activities was not pursued and reflected on due to the nature of the study. We, however, argue that an approach underpinned by action research in which farmers are involved in iterative planning–action–reflection cycles can be valuable in building capacity[51] to identify future risks on the basis of multi-decadal climate projections as well as appropriate risk management strategies. Further, we purposefully applied a qualitative approach because we were interested in exploring participants' perspectives, interpretations and nuances in the identification, assessment and management of future climate risks.

For participant recruitment, we employed three strategies. First, we sought assistance of an external agency, working in the outreach and extension of agricultural research in Australia. Participants were predominantly recruited via this approach. Second, we used existing professional contacts of the study team to identify potential participants, who were then invited to partake in interviews via email and telephone. Third, a snowball sampling method was used, in which interviewed participants identified other potential participants and made a connection with the study team. The invitation to participate in the study was accompanied by a brief project information sheet, outlining conditions of participation and privacy. We used a 'saturation' method[52] to determine the number of interviewees. We reached saturation after 24 interviews, meaning no new information was perceived to have emerged. State of residence, climatic zones, commodities and business type were considered for participant selection (see Supplementary Table 3 for participant characteristics). The number of participants was not intended to be representative of all Australian farmers. Engaging with a small number of participants is common in qualitative research in which the objective is not to generalize but to generate new insights[53].

Data collection was performed via online interviews. A set of semi-structured questions were developed and pre-tested before use (a copy questionnaire is available in Supplementary Note 7). On average, interviews lasted an hour. With verbal consent from participants, all interviews were audio-recorded and professionally transcribed.

All transcripts were cleaned, verified and de-identified before uploading them to R software[54] for data analysis. We performed thematic analysis using the RQDA package[55], in which references made by participants against risk identification, risk assessment and risk management were separately assigned to codes[56]. All transcripts were read and re-read to form a general understanding of the key responses in relation to the study objectives. Similar meaning codes were then grouped together to generate themes within the three components of the framework. Although some argue that coding transcripts for data analysis by a single researcher is sufficient for qualitative research[57], we invited two additional researchers to review and comment on all the codes and themes. This helped to identify and resolve discrepancies[58] and resulted in recoding of the transcripts and redefining the themes. Codes used to visualize the results are publicly available on CSIRO's Data Access Portal[59].

Transcripts were coded and recorded five times to generate the final themes for reporting. In the first attempt, 33 subthemes were generated against the five themes of risk identification (short term, pre-MyCV and post-MyCV), risk assessment and risk management. Several subthemes were merged, and new subthemes were created after they were reviewed by two additional researchers. On the fifth attempt, subthemes were reduced to 18, which the researchers agreed and presented in this manuscript. The involvement of multiple researchers and comparing notes were useful to harmonize the coding process and added rigour to the data analysis as justifications for decisions about code allocations were made more transparent and consistent[60]. For visualization of the results, we documented how many times each theme has been discussed by participants in the interviews. As this study is exploratory in nature, we did not highlight the prominence of themes, based on their frequency of occurrence, in the results. The R packages used for visualizations are provided in Supplementary Note 8.

Limitations

Our study demonstrated that participants were able to identify future risks on the basis of MyCV. While we cannot conclusively single out the impact of the MyCV interface, we are confident that the process of discussing risks from MyCV data played an important role in the apparent change in risk perceptions.

Although all of the participants identified risk management decisions, this research was not able to return to assess whether these were in fact implemented. Further work is planned to continue this approach and to return to follow up with outcomes. We suggest that others could utilize a similar risk analysis framing to engage with farmers to identify risk management plans and assess outcomes. Dissemination of these findings could demonstrate examples of climate adaptation, of which empirical examples, learnings and lessons for scaling out are still much needed[3,5]. Additionally, while our qualitative research suggests that the use of multi-decadal projections may be consistent across businesses, climatic zones and commodities, further research is warranted to statistically validate these findings.

Ethical statement

Ethics clearance was obtained from CSIRO's Human Research Ethics Committee (ethics application ID: 001/21).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The interview data are confidential and not publicly available because they contain personal information of participants. Data to reproduce the visualizations are publicly available on CSIRO's Data Access Portal (https://doi.org/10.25919/a178-fp44).

Code availability

No computer-assisted algorithms were used in data analysis to generate codes and themes. Codes used to visualize the results are publicly available on CSIRO's Data Access Portal (https://doi.org/10.25919/a178-fp44).

References

48. Kemmis, S. What is to be done? The place of action research. *Educ. Action Res.* **18**, 417–427 (2010).
49. Costello, P. J. M. *Action Research* (Bloomsbury, 2003).
50. Minichiello, V., Aroni, R. & Hays, T. *In-Depth Interviewing: Principles, Techniques, Analysis* 3rd edn (Pearson Education Australia, 2008).
51. Mapfumo, P. et al. Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa. *Environ. Dev.* **5**, 6–22 (2013).
52. Miles, M. B. & Huberman, A. M., *Qualitative Data Analysis: An Expanded Sourcebook* 2nd edn (Sage Publications, 1994).
53. Powers of qualitative research. *Nat. Clim. Change* **11**, 717 (2021).
54. R Core Team. *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, 2018).
55. Huang, R. *RQDA: R-Based Qualitative Data Analysis. R Package Version 0.3.1* ((R Foundation for Statistical Computing, 2018).
56. Bradley, E. H., Curry, L. A. & Devers, K. J. Qualitative data analysis for health services research: developing taxonomy, themes, and theory. *Health Services Res.* **42**, 1758–1772 (2007).
57. Janesick, V. in *Strategies of Qualitative Inquiry* (eds Denzin, N. & Lincoln, Y. S.) 46–79 (Sage Publications, 2003).
58. Braun, V. & Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **3**, 77–101 (2006).
59. Malakar, Y. et al. *R Codes Used in the Paper Entitled 'Multi-decadal Climate Services Help Farmers Assess and Manage Future Risks'* (CSIRO, 2024).
60. Morse, J. M. et al. Verification strategies for establishing reliability and validity in qualitative research. *Int. J. Qual. Methods* **1**, 13–22 (2002).

Acknowledgements

This study was funded by the Future Drought Fund, administered by the Department of Agriculture Fisheries and Forestry (DAFF). We thank the CSA programme team for their support in conducting this study and give particular thanks to all of the farmers who were interviewed. We are also thankful to S. Clary from FarmLink Research for helping us recruit interview participants.

Author contributions

Y.M., A.F., S.F. and E.J. designed the study. Y.M. and S.S. conducted the interviews. Y.M. performed the data analysis, and S.S. and A.F. reviewed the codes. Y.M. wrote the first draft. S.S., A.F., S.F., E.J., R.D. and C.T. contributed to writing, reviewing and editing the manuscript.

Funding

Open access funding provided by CSIRO Library Services.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41558-024-02021-2.

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Peer review information *Nature Climate Change* thanks Junyu Lu, Pranay Ranjan and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Last updated by author(s): Apr 8, 2024

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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	Data for this study was collected through individual interviews with farmers, without the use of any data collection software.
Data analysis	R studio (version 4.2.1) was used to perform data analysis. The RQDA package (version 0.3-1) was used for coding the transcripts and identifying themes and sub-themes. The following packages were used for data manipulation for visualisation. 1. tidyverse (version 2.0.0) 2. networkD3 (version 0.4) 3. htmltools (version 0.5.5) 4. gridExtra (version 2.3) The codes used for producing visualizations are available on CSIRO's data access portal (https://doi.org/10.25919/a178-fp44)

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Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	The primary objective of this study was to explore if multi-decadal climate projections could help farmers to understand future climate risks and inform their farm risk management decisions. Therefore, this study was designed to collect farmers' perspectives irrespective of their sex or gender. Consequently, no disaggregated sex and gender data were used for analysis.
Population characteristics	See above
Recruitment	Participants for the study were recruited using three methods. Firstly, an external agency experienced in agricultural research outreach in Australia helped identify potential participants. Secondly, invitations were sent out through existing professional networks. Lastly, the snowball method was employed, where interviewed participants suggested other potential participants who were then contacted by the study team. All potential participants were reached out to via phone or email, and a Project Information Sheet (PIS) was included in the invitation emails. The PIS provided a brief description of the project, as well as privacy and consent information.
Ethics oversight	Ethics clearance was obtained from CSIRO's Human Research Ethics Committee (ethics application ID: 001/21).

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	The study design followed a qualitative inquiry approach. We interviewed Australian farmers using a participatory risk analysis framework to understand how farmers make on-farm risk management decisions across two timescales: (1) one day to six months; (2) 20+ years. My Climate View was used as a climate service to explore climate projections and identify future climate risks, assess their impacts, and develop measures to manage those impacts. This study was designed to compare future risks perceived by farmers before and after they were introduced to My Climate View.
Research sample	We carried out 24 semi-structured interviews. As an exploratory study, the aim was to include participants from various states, climatic zones, commodities, and businesses in Australia. States: New South Wales (3), Northern Territory (2), National (business operated in various states, 1), Queensland (6), South Australia (3), Tasmania (3), Victoria (2), Western Australia (4). Climatic zones: Tropical (2), Subtropical (8), Grassland (13), and Various (business operated in various climatic zones, 1) Commodities: Perennial crop (11), Mixed (livestock and crop, 6), Annual crop (5), and livestock (2) Businesses: Family farm (20) and Corporate (4) The study was not designed for statistical analysis, so the sample size is not representative of the overall population. Other demographic information (e.g., age) were not analyzed and hence not collected.
Sampling strategy	We did not perform any sample size calculations. Instead, we followed a 'saturation' method. This means that we continued to conduct interviews until we reached a point where no new themes or insights were emerging from the data. We assessed saturation by comparing the codes and themes generated from each interview and looking for patterns of repetition and completeness. We reached saturation after 24 interviews.

Data collection	All interviews were conducted either via Microsoft Teams or over the phone. The built-in recording function of Teams was used for those interviews, while a separate recording device was used for phone interviews. Each interview lasted approximately an hour. An established interview protocol was followed during the interviews, and notes were taken throughout.
Timing	The interviews took place between November 2022 and September 2023.
Data exclusions	No data were excluded from the analysis.
Non-participation	We sent out invitations to 30+ potential participants, of which 24 agreed to participate. The remaining invitees did not respond to our invitation. None of the participants who started the interview process dropped out or declined to continue with the study.
Randomization	This is an exploratory study. We used a qualitative approach of inquiry for data collection and analysis. This did not require to control covariates. Participants were purposefully chosen based on their climatic zones, commodities, and business. They were not allocated randomly.

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