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Original research article

Comparing established practice for short-term forecasts and emerging use of climate projections to identify opportunities for climate services in Australian agriculture

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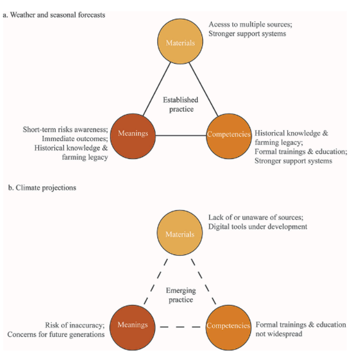
GRAPHICAL ABSTRACT



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ABSTRACT

The use of climate services in agriculture to improve both tactical and strategic management decisions on farm is an area of increasing societal interest and technological development in Australia, as climate change increases climate variability and risk. Yet the focus of most uses of climate services remains on weather and seasonal forecasts and tactical farm responses, with longer term climate projections less often empirically examined. In this paper we analyse 25 interviews with farmers in Australia and use social practice theory to compare farm risk management decisions utilising short-term weather forecasting and longer-term climate projection planning. We identify different elements of climate risk management as a social practice, looking particularly at materials (objects and tools), meanings (beliefs and thinking) and competencies (skills and knowledge) associated with climate services. We find that there are significant differences in how decisions are made using different temporal data scales and furthermore, that there are large gaps in the materials, meaning and competencies for the use of longer-term climate projections. This analysis allows us to clearly identify opportunities for the agricultural sector in Australia, and globally, to better support decisions in both weather and climate timeframes by treating these as distinctly different capabilities and addressing the different elements of social practice outlined here.

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Practical implications

The use of climate services has been recognised as a critical capability for farmers to adapt to climate change. Australia has made some progress in developing downscaled multi-decadal climate projections, but farmers still have limited knowledge of, and experience with, applying climate projections. Investments and policy developments are underway to expedite the development and use of climate services in Australian agriculture, for example, in My Climate View, a product of the Climate Services for Agriculture (CSA) program. CSA is a collaboration between CSIRO and the Bureau of Meteorology, part of the Australian Government's Future Drought Fund investment into the development of better climate information for Australia's agriculture sector. My Climate View presents agriculturally relevant historical and future climate information in one place so farmers can explore climate trends for specific commodities at a local scale. Using My Climate View as a case study, we explored how short-term forecasts and longer-term projections are used for different decisions and found key differences between the two, particularly the availability of technologies and experts, knowledge and skills to utilise weather, seasonal and climate information, and the beliefs and motivation for utilising this information in making on-farm risk management decisions.

In relation to the use of weather and seasonal forecasts, we found the digital tools and technologies to access this information were readily available. In fact, having more than one digital tool enabled farmers' agency and comparing the forecasts across different tools increased confidence in their decisions. Farmers were aware of short-term weather and seasonal risks, which was a key motivation for them to use weather and seasonal information to make on-farm risk management decisions. The skills and knowledge required to meaningfully utilise such information came from their experience, historical engagement in farm business, education, and institutional support systems.

The use of climate projections, on the other hand, was limited but emerging, which indicated several opportunities for the Australian (and global) agriculture sector, to better support farmers to benefit from projections to address future climate risks. To facilitate the use of climate projections, this study identifies three critical opportunities. First, limited knowledge and experience of using climate projections were reported. In the absence of climate projections, farmers have been using either historical data to extrapolate potential trends or their heuristics to make longer-term decisions. Making climate projections accessible for all farmers, therefore, is the first step. The provision of My Climate View, which was under development during the study phase, is a welcome start, but more needs to be done to increase the usability of such digital tools in Australia and globally. Second, the skills and knowledge farmers had to use short-term forecasts were not entirely transferable for using climate projections; hence, new competencies are found to be critical for the interpretation and subsequently the successful uptake of such projections to make future climate risk management decisions. This finding challenges the assumption that short-term forecasts and longer-term climate projection data are (or could be) used by farmers in the same way. Third, since future decisions are based on heuristics or other non-climate sources, understanding existing practices and support systems, and embedding them into the design of new climate data services is critical to facilitate the awareness of future climate risks.

1. Introduction

Farmers are increasingly affected by climate change (Crane et al., 2011; Donatti et al., 2019), leading to lower production, bankruptcy, and food insecurity (Bernauer and Schaffer, 2012; Komarek et al., 2020). The use of climate services has been recognised as key to addressing climate risks and building climate adaptive agricultural systems (Hansen et al., 2011; Magesa et al., 2023; Singh et al., 2018). Globally, the development of climate services targeting farmers has gained momentum (Ogega et al., 2020; Sánchez-García et al., 2022). The launch of the Global Framework for Climate Services emphasises the need for climate services for farmers to manage climate risks. According to Vaughan and Dessai (2014, p.1), "*Climate services involve the generation, provision, and contextualization of information and knowledge derived from climate research for decision making*". Climate services entail both short-term weather and seasonal forecasts and climate information on decadal timescales (Nkiaka et al., 2019); the distinction between short-term forecasts and longer-term climate projections is a crucial focus of this paper. In this paper we refer to 'short-term', as less than two weeks (weather) and no more than three months (seasonal) forecasts and 'longer-term' as several years and longer (multi-decadal) climate projections (Vaughan et al., 2018).

Despite the potential benefits of climate services to help inform risk management on farms (Hewitt et al., 2013; Shannon and Motha, 2015), empirical evidence has been mostly concentrated around the use of short-term forecasts, for example (Anshul et al., 2022; Chiputwa et al., 2020). Weather and seasonal forecasts are frequently used in operational decisions on farms, such as when to plant, schedule irrigation, or apply fertiliser (Austin et al., 2020; Hayman et al., 2012; Rickards and Howden, 2012). In addition, cropping cycles are mostly annual; hence, these types of farmers are primarily interested in knowing short-term forecasts as opposed to decadal climate projections (Shannon and Motha, 2015). Recently, there have been some attempts to articulate the value of longer-term climate projections (>20 years) in managing risks and opportunities, such as making decisions about future infrastructure investment, devising mitigation policies, and guiding adaptation choices (Hewitt and Stone, 2021).

Furthermore, generalised climate service products often require higher level interpretation to be operationalised, due to heterogenaiety of production types and decision contexts in agriculture (Klemm and McPherson, 2017). In response, a growing number of climate products seek to incorporate climate models with crop models, leading to the development of commodity-specific climate products e.g. Australia's Wine Future: A Climate Atlas | Wine Australia or the Med Gold tool for durham wheat in Europe (Dainelli et al., 2022). Yet despite growth in climate product offerings, the existing literature has yet to empirically explore the value proposition of climate projections in managing farmers' longer-term risks, and for farmers, the value proposition of using longer-term climate projections often remains unclear (Fleming et al., 2022; Vaughan et al., 2018).

Studies investigating why climate projections lack decision-making potential and their subsequent uptake by farmers are significnalty limited. This paper seeks to make a contribution by understanding the factors that influence farmers to use multi-decadal climate projections to make farm decisions. We do so by employing social practice theory as an analytical framework, which provides a novel contribution to the understanding of climate services, although it has begun to be explored in various agricultural contexts (Carolan, 2017; Higgins et al., 2017; Jakku et al., 2019; Rose et al., 2022). Social practice theory contributes to our understanding of the influence of social contexts and agency in human behaviour and social processes (Svennevik, 2022). It helps shed light on comparing different practices, such as the use of short-term and long-term climate information.

The use of social practice theory and practice-based approaches to enquiry are becoming more common in a range of application domains from sustainable energy (Malakar et al., 2018; Nicholls et al., 2020; Shove and Walker, 2014) to agriculture (Higgins et al., 2017; Rose et al., 2022), where scholars generate new knowledge about use contexts and technologies by focusing on the 'practice' of regular, daily tasks (Shove, 2010). In agriculture, social practice theory has been useful to identify unforeseen and unintended implications of technology innovation, when put into context on farm. For example, farmers traditional practice of repairing machinery was highlighted when manufacturers attempted to exert an exclusive right to repair and disrupted farmers' ability to "tinker" with their technology (Higgins et al., 2017).

In other examples, Carolan (2017) and Rijswijk et al. (2019) have examined the subtle and inexorable impacts of increasingly digital practices on farmers lives and identities, and Jakku et al. (2019) explored different perceptions and experiences of digital technology in the Australian grains industry and the role of trust in mediating changes to farm practices. Further, Kaiser and Burger (2022) engaged Swiss farmers to explore their crop protection practice and identify policy solutions that allow diverse practices for farmers to transition towards low-pesticide farming methods. Thus, social practice theory provides a valuable lens on ways in which the contextual practices of behaviour are established, reproduced or broken across space and time (Hargreaves, 2011). However, fewer examples exist which seek to understand climate services from a social practice theory perspective, and especially *longer-term* climate risk management practices and underpinning drivers. This paper focuses on Australian agriculture as a case study because of the considerable interest and investment underway in Australia to improve the use of climate services (Australian Government, 2021; Power et al., 2023).

The paper proceeds as follows. Section 2 describes the case study context. Section 3 elaborates social practice theory and the analytical framework employed in this study. The methods used to collect and analyse data are also detailed in Section 4. In Section 5 we present the results, exploring climate services and the context that enables or constrains their uses from a social practice theory lens. We discuss the findings in Section 6, highlighting key insights and recommendations of the study, and conclude the paper in Section 7.

2. Case study context – Climate services for Australia

The Australian agricultural industry has always had to cope with a variable climate and extremes of fires, floods and droughts, but climate change increases the severity and frequency of these shocks (Abram et al., 2021; Darbyshire et al., 2022; Hoffmann et al., 2019; Hughes et al., 2019; Stokes and Howden, 2010; Thamo et al., 2017). To build climate resilient agriculture systems, farmers are required to employ approaches such as risk transfer (Kath et al., 2018; Shannon and Motha, 2015), enterprise transformations (Mushtaq, 2018) along with adaption decisions (Park et al., 2012). In Australia, a number of climate service platforms have been made publicly available to support farmers make adaptation decisions, for example, Climate outlooks by the Bureau of Meteorology, Northern Australia Climate Program (https://www.nacp.org.au/), and Drought and Climate Adaptation Program (DCAP) (https://longpaddock.qld.gov.au/).

Although Australian climate projections have historically been made available since 1987, Whetton et al. (2016) emphasise the need for contextualised climate projections and guidance on how to use these projections by stakeholders to make adaptation decisions. In the last five years, Australia has made some progress in relation to climate services at both the policy and implementation level. At the policy level (national and state levels), Australia's National Climate Resilience and Adaptation Strategy (the strategy) envisions *"Australia to better anticipate, manage and adapt to climate change"* (Australian Government, 2021, p.6). One of the objectives that the strategy outlines is to improve the provision of climate services to support decision-making and develop a national climate services capability for Australia (NESP Earth Systems Climate Change Hub, 2021).

At the implementation level, in 2018 the Australian Government established the Future Drought Fund (FDF), now managed by the Department of Agriculture, Fisheries and Forestry (DAFF), to assist these sectors to adapt to drought and climate variability (DAFF, 2020; 2022). Part of this work includes funding $29 million toward the Climate Services for Agriculture (CSA) program from 2020 to 2024, jointly delivered by Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology (Fleming et al., 2022; Power et al., 2023). My Climate View is a product of the CSA program. My Climate View, a web-based tool (see https://myclimateview.com.au/), was developed under the CSA program for free public access that links localised historical climate data (1961–1990 and 1991–2020) and future projections for different periods (2016–2045, 2036–2065, and 2056–2085). My Climate View presents agriculturally relevant historical and future climate information in one place so farmers can explore climate trends for specific commodities at a local scale.

My Climate View is a valuable case study for comparing the use of short-term weather and seasonal forecasts and longer-term climate projections because it aims to help farmers use longer-term projections and offers historical and short-term seasonal forecast information (Fleming et al., 2022), so the comparison between short- and longer-term decision contexts can occur within the same tool. Furthermore, because My Climate View was under development, at the time of our study, insights from this study can be fed back and embedded into its development process.

3. Analytical framework

Social practice theory has its roots in the work of Bourdieu (1990) and Giddens (1984), gaining widespread recognition and application following the work of Theodore Schatzki (Schatzki, 2002) and Andreas Reckwitz (Reckwitz, 2002). Social practice theorists conceptualise how practices emerge, are sustained, evolve, and fade across time and space (Schatzki, 1996; Shove, 2010). The proponents of social practice theory argue that practice should be the focus of enquiry, rather than actors. Focusing on practice by decentring the individual is helpful because it sees behaviours as a reflection of socio-cultural traditions and norms, learned and passed on through contextual knowledge (Nicolini, 2012), rather than assuming actors to be utility-maximising and purely rational. In this respect social practice theory overcomes assumptions of rationality and linearity of decision making prevelent in alternative social theories such as Theory of Planned Behaviour (Ajzen, 1991), or Theory of Reasoned Action (Hale et al., 2002). This is particularly relevant and important to capture in farming, which is often a multi-generational practice steeped in cultural and traditional values connecting family, sense of place, community and identity (Rijswijk et al., 2019; Vanclay, 2004). Farming decisions can be based on hetrogenous non-linear factors including markets, animal welfare, weather, climate, tacit knowledge/intuition, and are suited to a more nuanced approach to analysis (Kaiser and Burger, 2022).

Schatzki (1996) first defined a practice as a *"nexus of doings and sayings" (p.89)*. Schatzki's definition highlights the interconnected nature of a practice as *nexus*. For Reckwitz (2002, p. 249), a practice is *"a routinized type of behaviour which consists of several elements, interconnected to one other"*. The terms *routine*, *behaviour* and *interconnected elements* are important in relation to the use of climate services in the 'practice' of weather and climate risk/s management. This occurs through processes of looking at weather forecasts and projections, relating this to likely impacts on farm (e.g. rainfall, heat, frost), and enacting behaviour to mitigate risks and capitalise on opportunities (e.g. planting, irrigating, harvesting). It is well-argued that understanding human behaviour is crucial in tackling climate risks (Kurz et al., 2015). Here, using a social practice theory lens is useful because it enables the understanding of daily practices and routines, which are crucial to understanding behaviour (Reckwitz, 2002) and the interconnected elements that drive climate risk management outcomes.

According to Shove et al. (2012), the interconnected elements that constitute a practice can be broken down into materials, competencies and meanings, as shown in Fig. 1. *Materials* refers to physical entities such as objects, things, technologies, tools, hardware, and the human body. The availability of materials, however, does not create a practice. A car, for example, would not drive itself without a driver who has the required skills to drive. *Competencies,* therefore, refers to the know-how, skills, training and background knowledge required to operate materials in the given social context, and the motivation to do so. *Meanings* are beliefs and thinking, understood, developed and used within a social context, developed around the material and its use. These

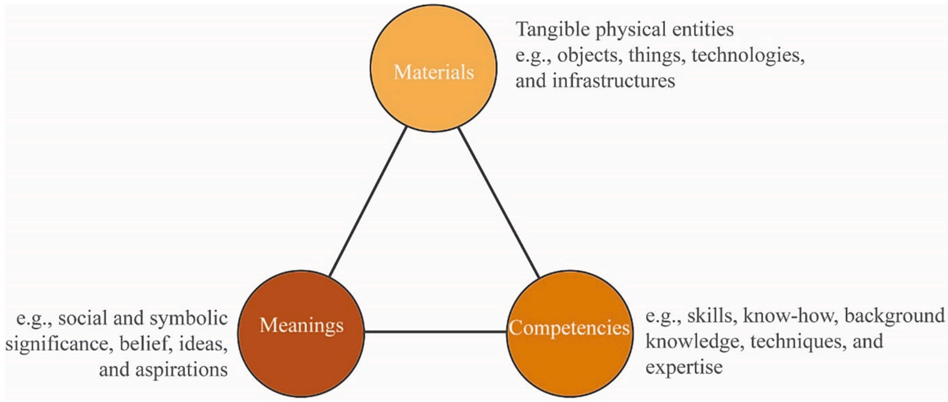

Fig. 1. Three interconnected elements of a practice: Meanings, Materials and Competencies.

interdependencies and the links between them are routinely reproduced as practices, which are reflected in human behaviour and habits. To reiterate, everything people do or say is a practice that has three constituted elements. A practice emerges when these elements come together, any change in the links between these elements results in change in the practice or the emergence of a new practice.

In light of this overview of social practice theory, we argue that understanding the use of climate services provides an opportunity to inform and support risk management practice. It requires materials such as weather monitoring devices (e.g., rain guages, thermometers, and radars), computers and algorithms, digital devices (for displaying forecasts and projections), and other technical resources. At least two types of competencies are then required. For example, to use these materials to *produce meaningful information* and furthermore, to be able to use *this information to make risk management decisions*. Our focus in this paper is the second. A principal aim of this study is to examine how the adoption and use of climate services takes place in risk management practice and explore its constituent elements. In so doing, we make a clear distinction between managing (1) short-term risks based on weather and seasonal forecasts and (2) future climate risks based on long-term projections. Having this distinction is important to understand how the three interrelated elements influence the use of short-term forecasts and long-term projections. Also, as we have alluded to earlier, the current literature falls short on documenting examples of farmers using long-term climate projections. This study makes a contribution to bridging this gap in scientific analysis – as future climate projections have increased relevance in the context of a changing climate – having the potential to support better climate risk management decisions.

4. Methods

4.1. Participant selection

For this paper, we sought to recruit participants from across Australia and across various agricultural commodity sub-sectors to capture diverse contexts. To do so, we employed three approaches. First, participants were predominantly recruited through the assistance of members of the CSA program working on outreach, engagement and facilitating connections to farmers for research. Second, the study team used their existing professional contacts to identify potential participants. Third, invitations to participate in the research were sought during webinars, demonstrations and other events organised by the CSA program. Ethics clearance was obtained prior to contacting potential participants (001/21). Invitations for participation were sent via emails, which was accompanied by project information sheets that explained the objectives of the project, conditions of participation, privacy, and the associated risks. Twenty-five participants took part in the study. To determine the sample size, we used a 'saturation' sampling method (Miles and Huberman, 1994). We reached saturation after 25 interviews, i.e., when little or no new information was emerging from the interviews. We also kept the sample size relatively low and interviewed participants across sectors, as a core objective was to collect in-depth qualitative data to understand farmers' practice but not to generalise the findings. Table 1 provides an overview of demographic information on the research participants (Livestock = beef, sheep, and pork; cropping = horticulture, viticulture, broadacre, and sugarcane). The study was exploratory in nature and hence the sample was broader than if we intended to test the effect of climate services as an intervention on a given sample. The relative lack of comparable state-based interventions at the time was advantageous, as this meant user-tailorable online multidecadal climate services was a new concept for participants. Consequently, the equal geographical and industry representation was not a requirement.

4.2. Data collection and analysis

The basic premise of social practice theory is to enable the understanding of decision-making contexts, including everyday habits and processes, norms and cultures, which can either work to enhance, or constrain the use of climate services. This analytical framework best aligns with deep qualitative engagement with research participants through a conversation about their perspectives, practices, and experiences. Consequently, we conducted semi-structured interviews for data collection. The interview questions covered a range of topics, opening with a brief introduction on the participants' background, their current use of weather and seasonal forecasts and tools as well as climate projections. A link to protype version of My Climate View (https://myclimateview.com.au/) was provided at the time of invitation to participants. Participants were invited to visit the website prior to the interviews. In the case that participants did not visit the website prior to their interview some questions related to the usability of the platform were omitted. On average, the interviews were 40 min long. All

Table 1
Participant characteristics.

Details	State	Commodity	Gender	Farm type
Participant numbers (25)	New South Wales (6) South Australia (4) Western Australia (4) Victoria (4) Queensland (3) Tasmania (2) Multiple states (2)	Livestock (10) Cropping (9) Dairy (3) Livestock & cropping (3)	Male (14) Female (11)	Family-owned (21) Corporate (4)

interviews were audio recorded with participant's consent and professionally transcribed for data analysis.

Our data analysis was guided by social practice theory. The three constituents of practice, materials, competencies, and meanings, were used to develop a coding framework. Using this framework, the interview transcripts were coded against materials, competencies, and meanings. This allowed us to identify different perceptions, experience, knowledge, and motivation relating to the use of climate services for risk management practices. As it is important for our focus to differentiate between weather and climate, we made a distinction between the discussion of 1) short-term weather and seasonal forecasts (1 day to 3 months) and 2) longer-term climate projections (20 + years) while analysing data. In doing so we were able to uncover the similarities, differences and interconnections between the materials, competencies, and meanings in relation to managing current and shorter term (weather) and longer-term, future (climate) risks.

Data analysis was performed in R software (R Core Team, 2018). The transcripts were cleaned, coverted to *'.txt'* fomat, and uploaded to the software. The R package for Qualitative Data Analysis (RQDA) was used for coding (Huang, 2018).

5. Results

5.1. Overview of practice elements associated with climate services

Our analysis of the interviews revealed that all participants (25) utilised weather and seasonal forecasts whereas a minority utilised climate projections (5). The results showed stronger links between the practice elements of materials, competencies, and meanings in relation to use of short-term forecasts than the use of longer-term projections, suggesting the former is an established short-term risk management practice and the latter is an emerging practice. The overview of the practice elements associated with short-term forecasts are depicted in Fig. 2a. We found that meanings were reflected through participants' short-term risk awareness to achieve immediate outcomes and their experiences in dealing with past weather and seasonal variability. Their farming legacy also acted as a motivation to reproduce the practice across different temporal scales. Participants had access to materials in the form of various digital tools and professional and institutional support systems. Competencies required to access and interpret such forecasts were acquired through their historical knowledge, training, education, and support systems.

The overview of the practice elements associated with longer-term projections are depicted in Fig. 2b. We found that meanings for using climate projections were not yet fully established, demonstrating that this is still a new practice. Longer-term climate risk awareness was limited and tended to be discounted by perceived risk of inaccuracies in longer-term climate projections and a lack of understanding about how the projected climate changes could or should influence decision-making in the present. Those who sought longer-term climate information said it helped them assess future climate risks and make adaptation decisions. Farm succession was also identified as one of the motivations for using climate projections. Materials in the form of digital tools were just beginning to be designed for use by land managers and were not particularly widespread, impeding consistent articulation of the subsequent benefits of climate projection information. We found that formal training and education were key competencies associated with climate projections, but they were not readily embedded or relevant to participants' farming knowledge and everyday practice. The detailed qualitative analysis of this synthesis is presented in the sections below.

5.2. Short-term forecasts

5.2.1. Meanings

All 25 participants discussed different themes of meanings related to their use of short-term forecasts, including their perceptions of different short-term risks, the farming knowledge that they acquired historically, and the legacy built up through intra-generational engagement in farming.

Short-term risks were described in relation to loss of production due to weather and seasonal variabilities such as lack of rainfall, too much rainfall over a short period, high humidity, and heat waves. The users of weather and seasonal forecasts used short-term forecasts to identify and make tactical risk management decisions, as explained by a horticulture farmer:

> "…we have quite [a] few big diseases that are based off rainfall events. Humidity and hotter weather can lead to disease outbreaks on our farm, so we've got to be careful as to looking at forecasts and what happens… It [weather forecasts] can allow us to apply a spray before the event and allows us to make sure that we've covered that risk." (F02).

Twenty-one farmers (of the 25 that we interviewed) had family-owned businesses. Some had taken over the farm from their parents, and some had worked on their parents' property before buying their own. Past engagement in a farm business created a farming 'legacy' where previous experiences, such as collecting weather data, formed a continuing norm. This routine then relates to the frequent use of short-term forecasts. The following quote by a livestock farmer regarding the collection of weather data demonstrates this practice:

> "…we've got [rainfall] records from 1962 when my farther-in-law owned the property, so it's very basic rain gauge…we have had [this property] over the last 20 years… he's [the husband] been doing it since he's owned the property." (F25).

Despite some scepticism around the accuracy of weather and seasonal forecasts, participants also expressed how accessing this information has become an everyday task. This informs us that such activities are performed without making a conscious choice to perform them. Participants spoke of checking weather information several times a day, depending on the season, as doing so has become a routine. A dairy farmer explained this as:

> "In terms of weather forecasts, we're looking at that, depending on time of year…through the months of October, November, [and] December, we're looking at those weather forecasts daily, and we're sort of projecting out to the week." (F23).

5.2.2. Materials

Materials in terms of access to digital technologies and professional and institutional support systems[1] were identified that influenced the use of short-term forecasts. All participants relied on digital sources for accessing weather and seasonal forecasts, including apps and web-based platforms on computers. Various sources for short-term forecasts were used, including digital tools operated by the Australian Government (e.g., the Bureau of Meteorology) and applications that use data provided by the Government (e.g., Willy Weather), private firms (e.g., Elders), and overseas companies (e.g., YR by Norwegian Meteorological Institute). Importantly, most farmers regularly used more than one source for two main reasons: (1) to seek different information; and (2) to cross-check and/or validate the information.

According to participants, different platforms had different capabilities, and hence, depending on their requirements, they would service different needs. This demonstrates how the information needs of farmers were being fulfilled by technologies, which exemplifies the social significance of such technologies. On the other hand, this also shows how skills to interpret weather information involve more than just use of existing technologies and demonstrate a complex interplay of farmer experience, perception, and synthesis of information. The use of various

[1] People and institutions are considered a part of the *materials* element.

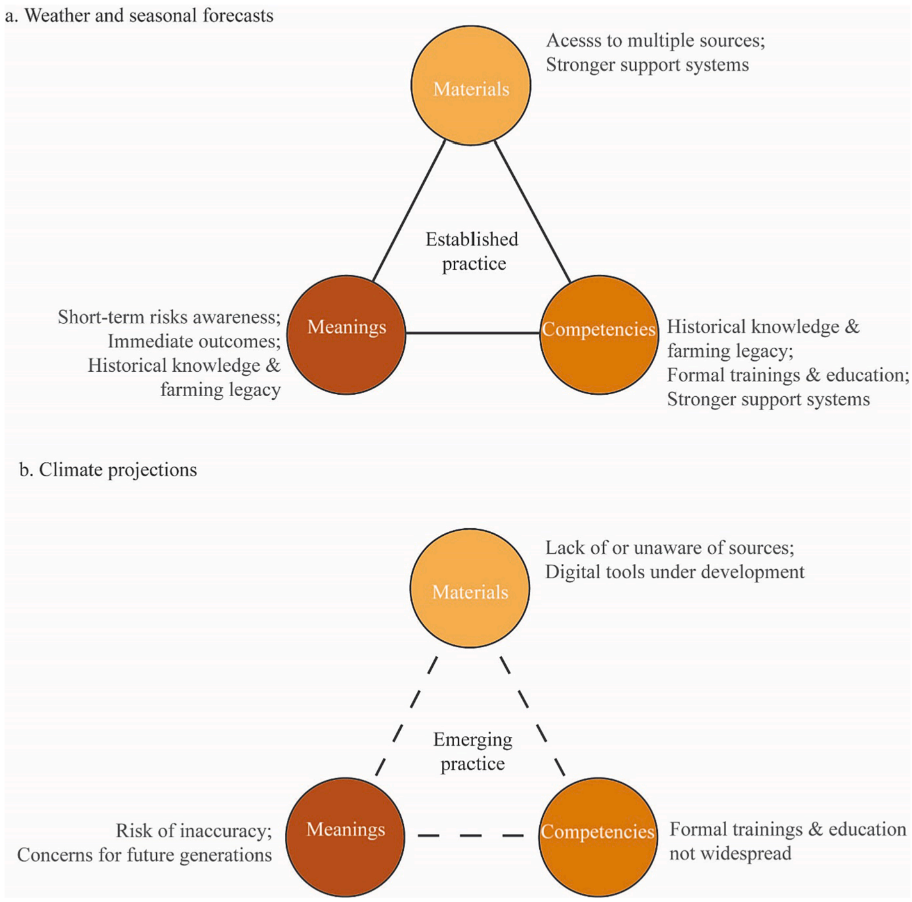

Fig. 2. The constituent elements of practice reflected in the use of (a) short-term forecasts and (b) climate projections.

sources to access weather information is described by one sheep farmer below:

> "…currently, I use two apps, BOM [the Bureau of Meteorology] and Weatherzone as sort of the weekly and a couple of week outlooks for on-farm planning in a weekly stage, and then CliMate for historical data and the sort of three-monthly outlook." (F05).

A range of participants spoke of the inherent uncertainties associated with weather and seasonal forecasts. According to participants, using multiple sources helped them to cross reference the information and have more confidence to act. In the quote below, a cropping and sheep farmer explained why he used three different sites.

> "…it's just WillyWeather, there's a US Navy website and Windy, I think…I guess just to see what [is] the general consensus with these other ones." (F04).

Existing support systems (professional and institutional) were found to be crucial in accessing weather and seasonal information. Most participants were part of agricultural groups or networks (ranging from local to national). One of the objectives of such groups/networks, as reported by the participants, was for sharing best practice, forming coalitions, friendships, and community service. Some groups/networks were attached to government agencies, and some were organised and managed by farmers. Some participants elucidated that such groups/networks disseminated weather and seasonal information, highlighted potential risks, and considered mitigation measures. Such support systems demonstrate how existing structures pass on values and knowledge in a particular context. Similarly, the relationship with government officials at local branches, e.g., weather stations and agriculture extension offices, was also crucial to access weather and seasonal information. According to participants, these local champions had expertise on the local context and would provide actionable information. Recalling their past communication with a local official at the weather station, a sugarcane farmer explained:

> "..I know, four or five years ago, if we were going to be putting a burn in and we didn't know if it was going to rain or not, we ring the forecasters…you sort of say, 'I'm situated right here,'…they'd say, 'No, it's [the rain] probably going to go around you, you should be pretty right…because local knowledge is paramount…" (F12).

5.2.3. Competencies

Competencies required to use short-term forecasts were found to be underpinned by historical knowledge, formal training, and education, and existing (professional and informal) support systems. Historical knowledge was discussed by all participants. Their knowledge served as competencies to engage with short-term forecasts. Participants discussed their experiences in tackling weather and seasonal variabilities, which were valuable in identifying competencies to minimise risk by monitoring short-term forecasts regularly. A livestock farmer described this as:

> "…weather is probably something that is the most unpredictable… over the years, we have looked very much at the weather patterns as they come…there is definitely a cyclical trend [observed] in [those] patterns…" (F11).

Participants spoke about how the collection and use of weather data has been ongoing for a long time, some of the processes for how this is done may have changed (e.g., automation), but the norms and knowledge to interpret the information remains the same. We found that weather information was either provided by external agencies, such as the Bureau of Meteorology and WillyWeather, generated locally on farm, or a combination of the two. At the farm level, some farmers have installed new equipment with advanced capabilities and user-friendly interfaces. This shows how past knowledge and practices were being updated along with technologies, as reflected in the quote below by a horticulture farmer:

> "Our new weather station is going electronic but then also you can print it out any time you want, so once it's installed, going forward, we'll have good access to weather records." (F07).

In addition to acquired tacit knowledge of their land, water and soil, formal training and education also assisted in developing the competencies required to translate short-term forecasts into actionable insights. Thus, some farmers mentioned their formal training, e.g., university or agricultural college, and how these qualifications helped them to make sense of data and data visualisations common to weather information:

> "I know me, coming straight out of [a] university, I'm so used to reading graphs and all of that…so looking at graphs, I was like, yeah, I understand this…" (F02).

Furthermore, most participants stated they engaged farm advisors, such as agronomists, vets, and animal feed nutritionists. These consultants provided advice on subject-specific issues, including pest management, fertiliser application, and disease control. Participants also highlighted that these advisors helped them interpret weather and seasonal information. In answering our question on the engagement of an agronomist to interpret and respond to weather information, a beef farmer elucidated:

> "Yeah, so they [agronomists] are usually quite good in saying, in mentioning that it looks like we're in for a wet season. So, really we should be getting crops in February and taking the risk down south. They seem to be well and truly on board with the climate 'looking out' [into future seasons] and they're usually not far off." (F14).

5.3. Longer-term projections

5.3.1. Meanings

Like the use of short-term forecasts, perceptions of risks were associated with the meanings and use of longer-term projections. Those who perceived longer-term risks as affecting their farm business into the future were more likely to be interested in climate projections. This group of participants explained that such projections were helpful to assess future climate risks and make adaptation decisions. A viticulturist explained future risks due to changing climate and how they're making longer-term decisions, as follows:

> "…we do look at longer-term decisions because you've got to look at what varieties we plant…there're some varieties I've got rid of because they can't handle extreme heat…and then there're some varieties that can't handle too much rain either." (F9).

In addition to future climate risks, participants identified farm succession and future investment as enablers to using climate projections, as exemplified in the following quote by a broadacre farmer:

> "…we have children that are interested in farming. So that succession is very important. And whether we look at gross expansion or contraction within the farm business, how does that look like? How do we invest our money? Do we look for higher rainfall areas if we're buying properties?" (F19).

Those who saw the value of climate projections but were not currently using them had slightly different longer-term risk perceptions. When asked about what impedes the use of longer-term climate projections, including the use of My Climate View, participants explained that the changes were happening too far in the future and raised the perceived risk of inaccuracy. Due to this, the confidence of these farmers in the projections was low, emphasised by a horticulture farmer:

> "I don't look too far ahead…If I knew it was going to be accurate, I probably would…I guess it's accuracy. I get that that's difficult; you're only using models to try and predict…" (F10).

5.3.2. Materials

The tools to access climate projections, as materials, were found to be limited or the awareness of existing projections were limited among the participants. My Climate View was under development at the time of this study. Those participants who reported considering climate projections in their farm business, used either published information (e.g., Australia's Wine Future: A Climate Atlas | Wine Australia and IPCC reports) or acted based on the extrapolation of trends based on historical patterns (e.g., Australian CliMate: (climateapp.net.au)) as a 'best guess'. This demonstrates that either there were not any platforms available for climate projections or participants were unaware of them or they were not suited to their needs. One livestock and cropping farmer, who had previously worked in a scientific institution, reported accessing the platform to validate their perception of future climate risk, reflected in the following quote:

> "I am looking at the Climate Services for Agriculture [now renamed as My Climate View] now…the [annual] rainfall's going to remain the same…but what is does is confirm [is] my perception that there's a slight decrease in autumn rainfall. Winter rainfall's going to be the same, but the spring rainfall is going to increase." (F22).

5.3.3. Competencies

Competencies to use climate projections were limited and linked with formal training, education, and the associated knowledge of participants. Those who reported accessing climate projections had connections with scientific institutions or studied aspects of climate change at a university. They described not only the value of individual actions to combat climate change, but also the need to adapt to manage future risks. Below is a quote from a sheep farmer who studied at a university and served as a board member on a natural resource management committee:

> "…there's a whole lot of globalisation and bigger climate issues but the reality is the focus that we know that we can influence and impact on is on-farm decisions that we make annually… I understood [that] for a lot of years, and supported farmers to be thinking about that adaptability need." (F15).

In relation to My Climate View, only one participant reported using climate projections, particularly for the purpose of validation as mentioned in the previous section. They stated they had no issue accessing the information and using the website. This may be because they were able to leverage their existing skills acquired through formal training and education. On the other hand, some participants cautioned us that others may find the data difficult to interpret, hence the tool should be accompanied by education materials and support, exemplified in the quote below:

> "…I know that someone who, like my dad…it's hard [for them] to read the graphs and understand them. They just want something that says, yes, this is going to happen, there's an upwards track. That's all they want to know. They don't want to read a whole heap of information and everything because they just don't have time." (F02).

6. Discussion

In this study, we aimed to explore how farmers make decisions from their use of climate services, and in what context these decisions take place, making a distinction between short and longer-term risks. Nash et al. (2017) argue that practices are socio-cultural entities and decisions are made in relation to the given socio-cultural context. Understanding the relationships between them is key to identify how such decisions take place and where opportunities exist to improve them. Social practice theory informs us that addressing weather and climate risks requires materials, meanings and competencies, through a suite of beliefs and knowledge, underpinned by traditions and norms (Carr, 2008; Galasso et al., 2021). However, it is not yet understood which materials, meanings and competencies are at work for climate services and how these compare for short versus longer-term decision-making. To contribute this new understanding of climate services, we applied a social practice theory lens to understand the decision-making context that farmers operate within and examine their use of climate services in risk management practice. Below we discuss two key findings.

6.1. Different constituents of practice for short-term forecasts and longer-term projections

The calls to facilitate the integration of climate services into risk management decisions are getting more attention (Boulanger and Penalba, 2010; Solaraju-Murali et al., 2022). Our study finds the constituent elements of practice for short-term forecasts and longer-term projections are not only different, but also the links between the elements are more established for the former and emerging for the latter. We, therefore, argue that the distinction between short-term forecasts and longer-term projections is an integral first step for the successful uptake of climate services and the subsequent application of adaptation pathways. As the number of online tools for weather and climate projections continue to grow, it is important for designers to recognise and address potential confusions in terminology. For example, a metareview by Vaughan et al. (2018) identifies and reviews 101 separate “climate service” initiatives, which variously comprised weather (1–2 days in the future), seasonal (3–6 months), decadal and multi-decadal studies, highlighting that even “climate” services include weather, which may be confusing to users who are not immediately aware of distinctions between weather and climate.

In relation to weather and seasonal forecasts, participants relied on multiple sources of digital tools (material); their skills to act on these forecasts were underpinned by historical knowledge, formal training, and support from community and experts (competence); and their awareness of short-term risks was a critical enabler to access these forecasts and use them to make tactical decisions (meaning). We found the links between these elements were established, leading to an established risk management practice associated with the use of short-term forecasts.

However, in relation to climate projections, the required awareness of future climate risks and the subsequent effects on farm business was rather weak or missing entirely (meaning); skills required to interpret projected data and support decision-making were either non-existent or insufficient (competence); and digital tools to access such projections were limited (material). This consequently led to a weak presence of meanings in using climate projections. Farm succession by subsequent generations is a dominant practice in Australia (Falkiner et al., 2017), and some participants, spoke about climate projections being helpful while considering succession plans of their business. Succession, however, is declining in some areas due to factors such as rural and youth migration (Cavicchioli et al., 2018), thereby affecting the potential use of climate projections. Some saw climate change impacts occurring too far in the future, a concept widely known as “psychological distance” (Loy and Spence, 2020), and raised the risk of inaccurate projections. Additionally, the lack of meaning is partly because farmers are dealing with annual and 5-year plans and understandably are unlikely to use climate projections frequently in their planning cycles. Industry-relevant and user-centred climate projection tools are relatively new and may be of particular interest to tree croppers and grape growers because of their longer crop cycles. Most participants therefore lacked background knowledge about the longer timeframes and relevance for decision making, thereby demonstrating a weaker link between meanings and competencies.

6.2. Strengthening practice links for longer-term climate projections

A core goal of climate projections in agricultural settings is to enable farmers to gauge future climate risks and plan measures to manage those risks ahead of time (Hewitt and Stone, 2021; Tall et al., 2018). To facilitate the use of climate projections in longer-term risk management, the links between the constituent elements of practice need to be strengthened. This requires significant work across all elements of materials, competencies, and meanings.

Without materials, no practice exists (Shove et al., 2012). Most participants had limited knowledge of, or experience with, accessing climate projection data. Those who considered climate change in their future decisions either used historical data or experiences to extrapolate potential trends while making future decisions. Farmers using their heuristics to make decisions about seasonal climate variability has been documented previously (McCown, 2012; McCown et al., 2012). What is important to note is the confidence that farmers get from comparing and cross checking the data across various platforms. This is obviously lacking in the case of climate projections because of the lack of awareness of and access to multiple sources of such projections, thereby suggesting a weak link between materials and meanings and reducing farmers confidence in the information that does exist. Therefore, first and foremost, access to climate projections should be made readily available. My Climate View is a welcome start, but globally more needs to be done. Additionally, our study suggests it is better to have access to more of these sources, as they help build farmers’ confidence. Because longer-term decisions are based on heuristics or other non-climate sources, it is important to recognise and support these existing practices in the design of new climate data services. The role of professionals involved in developing such services is to be cognisant of farmers’ decision-making context (Robertson and Murray-Prior, 2016). The low level of use and familiarity with longer-term projections suggests that a non-technical approach may be valuable to foster familiarity and non-expert use, thereby enabling engagement between those involved in developing, providing and using climate services in managing risks (Hewitt and Stone, 2021).

New innovations and skills are critical in addressing risks related to weather and climate (Zuccaro et al., 2020). This does not mean traditional knowledge is obsolete, as Hiwasaki et al. (2014) argue that traditions have a crucial role in managing such risks. Traditions, as firmly established social norms, give continuation to a practice (Nicolini, 2017), this was evident in case of short-term forecasts. Traditions can also act as barriers to change or adopt new practice. The use of climate projections for managing future climate risks is new. Trying something new and embedding that into practice comes with fear of getting it wrong; and hence, avoiding new practice can be seen as a risk aversion strategy (Malakar et al., 2018). It takes new skills to properly apply and interpret the information within the platform, and these skills can vary across farm businesses (Jakku et al., 2019). With limited previous experience or background knowledge meanings to use climate projections are constrained. This affects routines, and the subsequent existence of habits and behaviour (Halkier et al., 2011). New skills and capability is therefore critical for facilitating the use of climate projections as social practice.

As noted above, distinguishing short-term forecasts and climate projections is a critical first step in the adoption of the latter, as adaptation pathways in agriculture have different temporal planning horizons. This time scale distinction is not always clear and has been identified as a reason for difficulties in conversation about climate change (Robertson and Murray-Prior, 2016). Therefore, it is imperative to make climate science understandable to farmers (Sadras et al., 2020) and can be achieved by the process of co-design, co-development and co-delivery (Fleming et al., 2023). The extension and innovation system scholarship argues that awareness is insufficient for action (de Oca et al., 2021), but longer-term meaning making has the potential to empower users in conversations with others (Fleming et al., 2022). Consequently, discussion about future climate risks need to happen at the farm level, which, we argue, will likely overcome some of the challenges around the lack of awareness of future risks. Farmers' engagement with agricultural extension agencies, non-government agencies, farm advisors, scientists, and media are key for exchanging knowledge and learning (Kelly et al., 2020; Siregar and Crane, 2011; Stitzlein et al., 2020). Such engagements can be accompanied with formal or informal trainings to access, interpret, and subsequently enact climate projections.

7. Conclusion

This is an exploratory study; hence, we purposefully selected famers across a range of regions and sectors. It is likely that the regions that are already facing severe climate change impacts may view climate projections as being more useful or that fixed horticulture farmers such as tree croppers may be more likely to be motivated to use, or be already integrating, climate projections into their farm planning. We did not explore and compare the perspectives of farmers that belong to the same region or grow the same crop. This warrants future research, for which we believe the analytical framework of social practice theory would be a useful methodology.

This paper applies social practice theory to the problem of supporting farmers to manage risk by using weather and seasonal forecasts and climate projections to inform decisions. We found that, when making tactical decisions using weather and seasonal forecasts, farmers used multiple sources of information and utilised strong existing support networks, which were not currently available for strategic decisions using climate projections. Farm succession and future climate risk assessments were two motivations for some participants to consider longer-term climate projections. At the same time, we also found that concerns about inaccuracy of longer-term projections versus more immediate outcomes limited ability to act on projections. Finally, the competencies needed to interpret longer-term projections and translate these into farm management practices also need to be built. This may benefit from peer and social learning approaches as the level of familiarity of climate projections were low.

Using social practice theory, we are clearly able to identify opportunities to strengthen each of the material, meaning and competency elements of potential risk management practices and to highlight how a focus on building stronger links between these will enable climate projection services to be adopted and normalised as part of routine behaviour on farm. The practice of managing future climate risks using longer-term projections is not yet established due to weak links between meanings, materials, and competencies. The contribution that this paper makes is a rethink of the types of skills and support that is needed for the use of longer-term climate projections as opposed to short-term forecasts, especially in responding to future risks.

CRediT authorship contribution statement

Yuwan Malakar: Conceptualization, Methodology, Writing – original draft. **Aysha Fleming:** Writing – review & editing. **Simon Fielke:** Methodology, Writing – review & editing. **Stephen Snow:** Conceptualization, Methodology, Writing – review & editing. **Emma Jakku:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Yuwan Malakar reports financial support was provided by Australian Government Department of Agriculture Fisheries and Forestry.

Data availability

The data that has been used is confidential.

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