# User-centred design towards trust and engagement with agricultural climate services in Australia

Climate services in HCI

Stephen Snow

Environment, CSIRO, Brisbane, Australia. stephen.snow@csiro.au

Karen Wealands

Data 61, CSIRO, Melbourne, Australia.

Online climate service dashboards provide information about future climate in specific locations and guide agricultural adaptation by farmers. Adoption of climate services in agriculture is a key objective of technology developers. Yet, adoption of new technology and new decision-making processes are rarely straight-forward and depend on users' trust in a tool or provider. Drawing from interviews with 27 farmers and 16 agricultural advisors, we explore the relationship between trust in climate projections and perceptions of future use of a national Australian climate service dashboard called My Climate View. We find that: (1) Trust mediates use of climate services, but does not guarantee future use. (2) Trust can be dynamic and changeable, and hence agricultural advisors may be important agents for adoption among farmers. (3) Supporting farmers' engagement with climate services means recognising and catering for their heterogenous circumstances and differing levels of trust in future climate information. The field of Human-Computer Interaction (HCI) has extensive expertise with trust and engagement with technology, but has not (to date) engaged closely with climate services. We close by outlining further ways in which HCI might engage in climate service design and development.

CCS CONCEPTS Human-centered computing → Human computer interaction (HCI) → HCI design and evaluation methods→ User studies.

**Additional Keywords and Phrases:** Climate, climate services, weather, dashboard, visualisation, behaviour change, user-centred.

**ACM Reference Format:**

First Author's Name, Initials, and Last Name, Second Author's Name, Initials, and Last Name, and Third Author's Name, Initials, and Last Name. 2018. The Title of the Paper: ACM Conference Proceedings Manuscript Submission Template: This is the subtitle of the paper, this document both explains and embodies the submission format for authors using Word. In Woodstock '18: ACM Symposium on Neural Gaze Detection, June 03–05, 2018, Woodstock, NY. ACM, New York, NY, USA, 10 pages. NOTE: This block will be automatically generated when manuscripts are processed after acceptance.

## 1. INTRODUCTION

Climate services are technical systems that provide weather and climate-related information to inform decision making [83]. In agriculture, climate services encompass numerous applications, from weather information and crop advice delivered via SMS [87] to a growing range of comprehensive web-based dashboards providing location-specific seasonal forecasts and future climate information [15, 59, 86]. Climate services are shown to be capable of informing climate change adaptation decisions in agriculture [49], such as varietal selection, adoption of zero-till agriculture or water efficient irrigation technology [87]. In this respect as technical agents for behaviour change, climate services have much in common with cornerstones of HCI research such as eco-feedback dashboards [6, 24, 39], personal health informatics [58, 68], air quality feedback [41, 42, 71], and the behaviour change pursuits of "Sustainable HCI" [9, 17]. Yet to date, climate services have not been a focus for HCI researchers. A recent paper [70] articulates this knowledge gap in detail, outlining areas which HCI might contribute to climate services development, including (among others): (1) understanding users' needs and context, (2) contributing expertise in data visualisation, and (3) in the technical development of decision support tools [70].

In this paper, we present further areas in which HCI might contribute to climate services development. Namely, leveraging HCI expertise in users' trust of digital systems to better understand the conduits and barriers to use and adoption of climate services among agricultural stakeholders. Trust is an important pre-requisite to technology adoption [5] and human-centred approaches that involve designing for transparency and trust are becoming widespread, in AI-enabled systems [12], more usable and trustworthy mechanisms for gaining informed consent [50, 57], trust in intermediaries who provide or recommend technologies [47] and trust in relation to perceived accuracy of data [88]. These last two capabilities are of particular importance to climate service development, where climate change in Australia remains politicised [21]; deliberate attempts to discredit future climate projections abound [38], and some Australians still harbour doubts about the existence of climate change [36]. Additionally, less is known about users' interactions with multi-decadal climate services (i.e. projections out to 2050-2070), compared to shorter-scale climate services such as seasonal and within-season climate information [53, 82]. User-tailorable multi-decadal climate projections represent a different means of interacting with future climate projections relative to the previous norm of climate information presented in static formats such as papers or reports [63]. This paper explores the relationship between trust and expected future use of multi-decadal (i.e. projections out to 2070) online climate services for agriculture. Drawing from 43 in-depth interviews with farmers and agricultural advisors, we unpack the complex relationship between trust and intended future use of My Climate View[1]: an online dashboard which allows users to explore commodity-specific future climate parameters for their location. We find that trust in climate projections is related to -but not a guarantee of- future use of the dashboard. Advisors reported a generally higher level of trust in the information compared to farmers, are already recognised as "brokers" of knowledge, [43] and like others [31, 47], our findings suggest advisors represent an important pathway to greater trust and adoption of climate services among farmers. We close with implications for how HCI might assist in climate services design and development including building trust and legitimacy in future climate information for agriculture.

## 2. BACKGROUND

### 2.1 Agriculture in HCI

Agricultural adaptation to climate change is central to global food security. It is a focus for governments world-wide and a key priority for the United Nations [81]. Yet relative to other critical application areas such as healthcare [7], exercise [74], sustainability [9] and social justice [16, 20], agriculture and agricultural adaptation is identified as an area deserving of greater engagement from HCI expertise [70]. Existing HCI engagements in agriculture include technology for development (e.g. ICT4D) [35, 85], robotics and autonomous systems in agriculture [44, 69], discovery and design work with farmers to help them consider options in new environmental markets [78, 79], food systems research including smart farming [18], human-food interaction [2, 62], urban agriculture (e.g. permaculture, city farms [51]) and "rural HCI" [32] which seeks to *"…productively advance understanding of what rurality is, and how it matters for sociotechnical systems"* [32:1]. Climate services on the other hand are highlighted as a knowledge gap for HCI research, where Rigby & Priest [70], through a systematic literature review, found only two papers from HCI venues engaged with climate services. A rationale for greater cross-over exists in climate services literature, which outlines a gap between "useful" versus "usable" climate services [66] and a prevalent tendency for climate services design to be focused on optimising data provision rather than engaging deeply with user' information needs and use contexts [23].

### 2.2 Climate services 'unpersuaded'

Climate services share similarities with other dashboards for behaviour change such as eco-feedback (e.g. digital feedback on energy use) [6, 39, 52], water use [25, 46], and rubbish and recycling monitoring and feedback [10, 61], which are staples of HCI research. A trend in both these fields has been the progressive realisation of the limits of persuasive design as an agent for behaviour change in complex settings. Brynjarsdottir et al. argues the *"…framing of sustainability as the optimization of simple metrics places technologies incorrectly as objective arbiters…"* over often much more complex issues [11]. This research helped refocus energy use feedback design beyond its previously (almost) ubiquitous goal of motivating energy saving behaviour change toward understanding how it might better support individual reflection [77] and better engage children and increase families' energy literacy [1]. Relatedly, social science research in agriculture has witnessed a trend away from a linear view of "technology transfer" where agricultural technology is "transferred" from "experts" to farmers, toward designing technology which better supports decisions rather than attempting to influence decisions [45]. In other words: *"Making farming more sustainable by*

[1] www.myclimateview.com.au

*helping farmers to decide rather than telling them what to do"* [45:1]. User-centred approaches to design in agriculture are becoming more mainstream, where clear failures to take into account farmers' experiential, tacit knowledge and context in design *"…contributes to farmers' loss of trust in scientific and government institutions and difficulties […] in achieving engagement or adoption"* [34:194]. Several recent examples of climate services development follow user-centred approaches to design to better understand user needs and support decision making, in a way that does not involve suggesting courses of action based on the information [15, 66, 80].

### 2.3 Adoption

Adoption represents a central end-goal of agricultural technology and technology design more generally [3, 60]. Originally understood as a linear process of development and diffusion [73], adoption of agricultural technology is increasingly recognised as a more complex and non-linear process in which users may trial, adopt, disengage, readopt [60], domesticate, modify, or hack technologies to suit their own situations [27]. User-centred design is an integral and important pathway to adoption, where users are more likely to adopt and continue to use technology which matches their needs and abilities [66]. Lindlay et al. [48] map out this parallel evolution of thought around adoption in HCI and social science literature, where initial understandings of adoption as determined by intrinsic motivations (e.g. Technology Acceptance Model), shifted toward understanding use of technology as situated in multiple contexts, and socially constructed (e.g. Situated Action, Social Construction of Technology).

In agriculture specifically, intermediaries such as farm advisors, agronomists and extension officers play a central role in adoption and farmers are more likely to adopt a technology or agricultural practice if it is recommended by their advisor [19]. Advisors act as "brokers" of knowledge and innovation and represent a key source of influence in decision making and an important pathway to adoption of practices and technology [43]. Advisors work alongside farmers and are a trusted source of advice on both shorter-term tactical decisions (e.g. what to plant, when to irrigate) and longer-term investment decisions (e.g. investments in drainage, technology and machinery) [67]. Because of their existing advice role and often close and trusted relationships with farmers, advisors are identified as important *"climate information intermediaries"* [31:84], who are excellently placed to help contextualise future climate information with farmers and help inform adaptation decisions and responses to future climate [31]. Compared to farmers, advisors are more likely to be aware of available climate-related decision support technology, and are more likely to use and recommend them [49].

### 2.4 Trust as a pre-requisite to use of technical systems

The identification of advisors as "climate information intermediaries" relates to the high level of trust between farmers and advisors [31]. Yet for this role to be effective, both parties must trust the data in the first place. Trust and use of technology are fundamentally related. In relation to agricultural technology and data, farmers' willingness to share data is substantially affected by perceptions of who will benefit from access to the data and famers may be unwilling to share data when benefits are perceived as favouring big business or technology companies rather than the farmers themselves [64]. These findings mirror those from HCI, where users are less likely to share energy use data [14], health data [7, 29] and other personal informatics [55] when they do not trust the processes or implications of sharing data. In relation to new and unfamiliar technology, Faas et al. [22] discusses the importance of "calibrating trust", i.e. closing the gap between users' trust in a technology and the system's actual capabilities. This is particularly important with respect to new and emergent technologies, where trust in a new technology is most likely to be built on a limited understandings of its functions or capabilities [22].

Use of -and trust in- technology is also strongly mediated by the perceived accuracy of information [64, 89]. The perceived accuracy of weather forecasts is an important determinant of their future use by farmers [76]. Farmers were found to regularly trial new weather apps and continue to use (or not use) them depending on their experience of the observed weather playing out as the forecast had predicted [76]. Yet trust in long-term climate projections is more complex. Firstly, because this rapid validation of "accuracy" is not possible for projections 30-50 years in the future, and secondly due to the politicised nature of climate change and climate projections [72], and the many successful attempts to discredit future climate projections [38]. Accordingly, productive discussions regarding future climate projections, and adaptation decisions are found to be most effective when framed in terms of future resilience and profitability and not framed as responses to climate change [28]. Given trust is identified as a factor affecting use of technology, the aim of this paper is to map the relationship between trust and expected future use of My Climate View. Using semi-structured qualitative interviews allows us to unpack these relationships in some detail and use these findings to inform the design of My Climate View and future climate services.

## 3. MY CLIMATE VIEW

My Climate View is a publicly available web-based tool providing *"…Australian farmers with tailored insights into their changing climate"*[2] out to 2070. It is developed and delivered by CSIRO and the Bureau of Meteorology, funded by the Australian Government's Future Drought Fund [13]. On the website's landing page (Figure 1) users select their location, their agricultural commodity (or alternatively "general climate factors") and receive future climate information that is tailored to their location and commodity. Its target user group is agricultural stakeholders including farmers and farm advisors, but it is also intended to support a wider range of users. The tool supports 22 commodities as of July 2024, with further commodities progressively added [13]. Following a substantive period of prototyping and user testing, it is currently live, in a phase of ongoing product improvement, where user feedback continues to be elicited and acted upon. Users can submit their own feedback on the website via the "Give Feedback" button (top right of Figure 1).

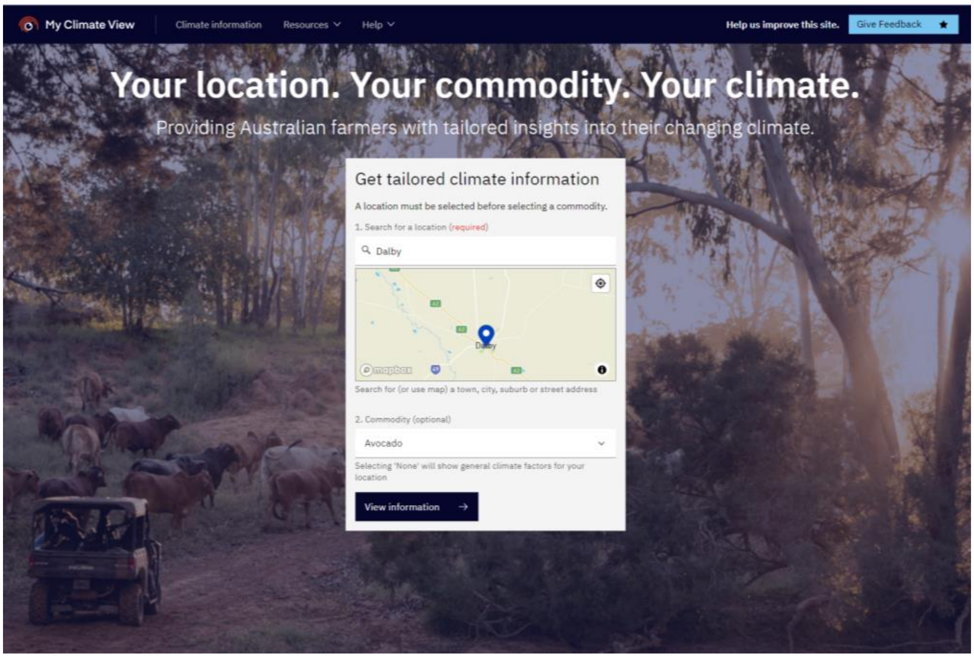


**Figure 1: My Climate View landing page**

Because of its ongoing development at the time of writing, the version of My Climate View that was shown to users as part of this study (January-November 2023) is now superseded by the current product, found online at http://myclimateview.com.au. The version discussed with users was called "Climate Services for Agriculture" (screenshots Appendix A). The interaction flow is the same between versions, where users first select their location and commodity and the same information is communicated, but the presentation of the climate information was relatively more complex in the initial version (Appendix A). This earlier version also featured a limited seasonal outlook, however, our focus in this paper is on attitudes towards and use of the future climate projections specifically. In both versions, the source of the climate information is the same, where past temperature and rainfall data are sourced from the Bureau of Meteorology and future projections are sourced from the Climate Change in Australia Application-Ready Data[3].

[2] http://myclimateview.com.au
[3] https://www.climatechangeinaustralia.gov.au/en/obtain-data/application-ready-data/eight-climate-models-data/

## 4. METHOD

In-depth semi-structured interviews were undertaken with 27 farmers and 16 advisors between January-November 2023 with the aim of gathering insights into expected uses, possible use contexts, usability, and pain points or misunderstandings in the use of My Climate View. The semi-structured interview format and general questions allowed exploration of values and expected future use and although not a central line of questioning, trust was an emergent theme relating to both weather forecasting and in relation to the My Climate View projections. The interviews represent a qualitative exploration of use cases for My Climate View and are not intended to be representative of Australia's entire farming population.

### 4.1. Sampling

A wide sample of farm types across a wide geographic area was sought. No quotas for farm type were imposed, nor were there any restrictions on recruitment other than excluding those for whom farming was not a primary income (e.g. hobby farmers, community gardeners). Sampling for farmers and advisors involved approaching those with publicly available contact information online, snowball sampling, contacts made through agricultural field days and workshops and limited researcher contacts. Sampling was additionally assisted by Farmlink (an agricultural research and extension agency). The research was approved by and conducted in accordance with CSIRO's Social and Interdisciplinary Science Human Research Ethics Committee (approval number: 001/21).

### 4.2. Participants

The 27 farmer participants comprised 24 owner-operators of family-owned farms and three area managers or scientists from corporate farms with operations spread over a wide area or interstate. Farms were located throughout Queensland, Northern New South Wales and the "Top End" of the Northern Territory, covering a variety of climatic zones from the Tropical Savannah climate of the Top End, the high rainfall Queensland wet tropics to the more temperate wine growing regions of Southern Queensland. Growers varied in terms of their primary commodity, including 6 involved in perennial horticulture (e.g. tree crops), 3 annual horticulture (e.g. vegetables), 5 broadacre or mixed crop, 4 winegrape, 4 beef, 3 sugarcane, 1 dairy and 1 lucerne (previously horticulture). This North Eastern Australian sample means certain significant parts of Australia's agricultural sector is not covered, such as the WA Wheatbelt or SA wine regions. Advisors comprised representatives of Australia's Drought Resilience Adoption and Innovation Hubs[4] (hereafter: "hubs"), agronomists, and one rural financial counsellor. Advisors were also located primarily throughout Queensland, with one viticultural advisor located in South Australia (Table 1).

Table 1: Participants and interview codes

| Year | Participant roles and interview codes | Number of participants |
|---|---|---|
| **2023** | Farmers (F1-F27) | 27 |
| | Agronomic and industry advisors (A1-A16) | 16 |
| | **Total interviews** | 43 |

### 4.3. Protocol

All farmer interviews were facilitated by the lead author of this paper, while advisor interviews were facilitated by three different social scientists on the project team. All interviews took place over the phone or online. Ethical consent documents were shared with those who expressed an interest in participating in the interviews, along with a link to the My Climate View website and an invitation to schedule a convenient time for the interview. Verbal consent was additionally gathered at the start of each interview. All participants were requested to explore the website prior to the interview, where we wanted to gather users' first impressions of the interface, rather than introducing it via a more curated demonstration. Interviews involved general questions relating to the nature of their farming operation, their existing use of weather forecasts and seasonal outlook information before discussing My Climate View. All interviews

[4] https://www.agriculture.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/research-adoption-program/adoption-innovation-hubs

then involved a short demonstration by the researcher to recap the key features (to ensure a baseline of knowledge and account for different depths of engagement on participants' own prior visits), followed by asking about participants' experiences and thoughts on My Climate View. These included eliciting their attitudes, likes, dislikes, potential uses and any usability issues, confusions, and pain points in using My Climate View. Interviews lasted between 25 and 90 minutes with the majority between 50-60 minutes. One of the 27 participants had seen a very early prototype of My Climate View, the remaining 26 had not heard of My Climate View prior.

### 4.4. Analysis

Interview audio was transcribed and de-identified. Transcripts were analysed using Nvivo qualitative analysis software. Demographic data and short-answer responses were tabulated separately. Reflexive thematic analysis following Braun and Clarke (2022) was applied to identify emergent themes. This process involves familiarisation, coding, collating codes into themes, review and refinement of themes [8]. Because different researchers coded the advisor interviews relative to farmer interviews, the refinement of themes stage involved comparison of codes between the farmer interviews versus advisor interviews.

Trust emerged as a key theme within both sets of interviews despite not being a central line of questioning in either. Many farmers brought up trust voluntarily, where trust emerged in relation to weather forecasts as well as a mediator of expected future use of My Climate View, the latter which was asked directly: *"Do you expect to use My Climate View in the future?"*. Accordingly, a further stage of thematic analysis was conducted focusing on trust, which led to the creation of the axis used to map participants with relation to trust and future use of My Climate View (Figures 2-3). This matrix does not attempt to capture the full complexity or completeness of farmers' perceptions towards projections of future climate. It does, however, provide a mapping of participants against two factors directly related to adoption- i.e. trust and use, and the semi-structured methodology allows us to further unpack these relationships through qualitative findings.

## 5. FINDINGS

The conversations touched on use and perceptions of farm type and existing use of shorter-term weather forecasts (farmers only), before focusing on perceptions and attitudes towards My Climate View (farmers and advisors). We focus on responses toward My Climate View from both farmers and advisors.

### 5.1. Farmers

**Trust and expected use of My Climate View**

All farmers were aware of general future climate projections disseminated via media, grower groups or advice networks, and five had independently looked up climate projections online in the past. However, none of the participants had experience of climate projections that could be tailored to their commodity, meaning that My Climate View was our farming participants' first experience of user-tailorable multi-decadal climate information. Because farmers were not already users of multi-decadal climate information, we concentrated on participants' descriptions of *expected future use* of My Climate View.

Overall, 16 of the 27 farmers expected to use My Climate View in the future and 20 more or less trusted the information, compared to only seven who expressed an overt distrust of the information. Participant responses point to the range and complexity of issues affecting trust and use of multi-decadal projections. Figure 2 below indicatively maps farmers according to their perceptions of trust and expectations of future use of the My Climate View dashboard. Both axes represent a continuum, though we found trust fell into one of three broad categories on this continuum: (1) explicit or implicit trust in the system exemplified by intended future use, (2) general trust despite circumspection associated with future projections, e.g. taking the projections with *"a grain of salt"*, (3) distrust of the projections- covering distrust through to complete disillusionment with meteorological and climatological science to the far left (Figure 2). Participants' positions on the axes should be seen as point-in-time and potentially changeable, which we revisit in the Discussion.

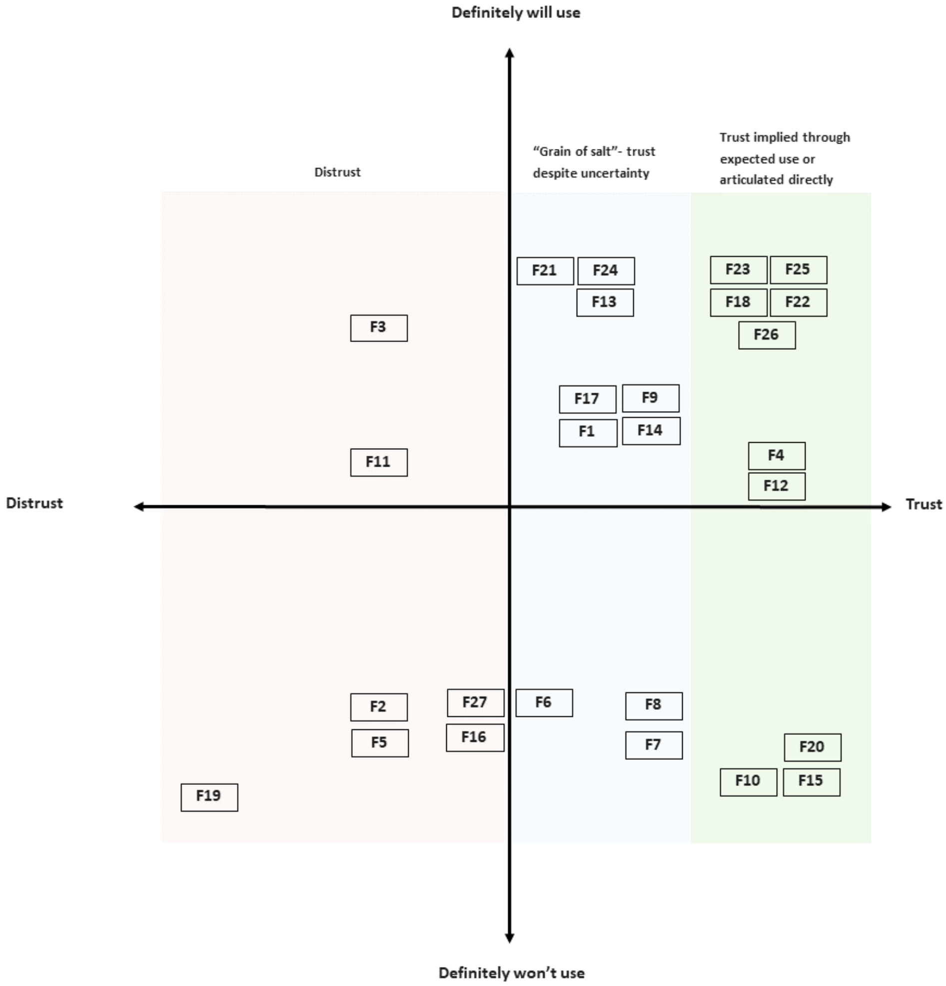


**Figure 2: Farmers plotted according to their trust in My Climate View data (horizontal axis) and expected future use of My Climate View (vertical axis)**

**Use, values and trust (Above the line):** Overall, My Climate View was well received and generally trusted, where only seven participants expressed an active distrust in the information provided. Farmers in the top-right quadrant of Figure 2 trusted the information presented by My Climate View and expected to use it in the future. Participants described diverse use cases for the information. These included identifying how My Climate View helped them better conceptualise future risks concerned with water availability (F1, F4, F9, F23, F24), the risk of warmer winter temperatures affecting fruit flowering and production (F13, F18, F25) and the need to consider adapting varieties or management practices in the future (F9, F13). Farmers mentioned the value of the information as a basis for their company's scenario planning (F23) or supporting documents for grants or loan applications (F24). Given trust was not a direct interview question, in several responses trust in the projections was implied through participants' description of the value of the projections to them and their expectations to operationalise them subsequently for farm planning.

Data "accuracy" or uncertainty was raised by several participants, which emerged as a mediator of trust. F1, F4, F22, F26 were conscious of the inherent uncertainties in future forecasts and projections (blue panel, Figure 2). These farmers were wary of taking the climate projections as "gospel", but still considered them valid points of reference for future decisions and still intended to use the website in the future.

> *"I think it's got merit in it. […] It's a prediction, so don't take it as gospel, but use it as a tool to maybe make some basic plans".* (F21)

*"I won't put all my faith in that forecast. It is the experience with being disappointed, I suppose, which has changed my outlook on it. [Yet] I like to know the long-term, yeah, […] because you want the long-term information so you can plan, and see what happens"* (F1)

Interestingly, two farmers expected to use My Climate View in the future despite expressing a distrust of the data and skepticism about emissions as a driver of future climate (top left quadrant of Figure 2). F11 remarked: *"Yeah, I'm still on fence, I don't know […] I'm a bit skeptical when you include the emissions component" (F11),* yet also considered they would still likely check in on it every year: *"We do the forage budget in May, so probably when I'm looking at that, I'd drop down the website and jump on then and just see if anything is changed, or… Yeah, I'd probably just, it'd be like a once a year thing" (F11).* Similarly, F3 who believed the science behind the projections was not proven, still expected to keep an eye on projections over time: *"I'd look at it [again] but wouldn't make decisions off it. It's not proven" (F3)*. These two participants' intention to continue to monitor the projections despite actively distrusting them hints that their distrust may be changeable in the future.

Distrust in the data was consequential to non-use in three cases (F2, F5 and F19). F2, F5, were enthusiastic users of weather forecasts, but did not believe it was feasible to project climate so far into the future, owing in part to a distrust of greenhouse gas emissions as a driver of climate. F2 described themselves as a "climate cycle guy". F5 wasn't convinced of greenhouse gas emissions as a driver of future climate: *"No one knows exactly what's going to happen. And around the emissions and that, that's all - It's only models. No one knows exactly what's going to happen" (F5).* F19 fostered a more extreme disillusionment with any weather forecasting or climate projection science:

*"'Climate trends'. You know, it's just such spiffy, airy-fairy information. I mean, it means nothing. […] I don't trust it. It hasn't been accurate for years. None of it's been accurate. I mean I wouldn't know where this has come from, this information anyway. I don't put enough confidence in the predictions or the seasonal charts or anything." (F19)*

**Reasons for expected non-use (below the horizonal line, Figure 2):** Reasons for anticipated non-use of My Climate View in the future were diverse and extended far beyond trust or distrust of the information. F15 and F20 were both were seeking to exit agriculture in the coming years, explaining that the projections were simply not relevant to them at their current life stage, even if they may have been in the past: *"I'd have loved it [My Climate View] 20 years ago when we were starting out […] now I'm 74 (F15).*

*"We did have a business plan, partly in the head, partly on paper, but it's actually been scrapped now. We do have a neighbour that is very interested in obtaining [purchasing] portions [of the farm] and we plan to work with them" (F20)*

F27 felt it is not feasible to accurately project climatic variables so far in the future. Yet their reasons for not expecting to use My Climate View related much more to their perceptions about the limited value of repeated visits to the website than their doubts about the "accuracy" of the projections:

*"Yes it's interesting to look at it a point in time now, but if I came back next year and looked at it, am I really going to see anything different than what I'm seeing now? […] There's not enough that's potentially going to change for me to want me to come back and look at it in six months' time or 12 months' time". (F27)*

Similarly, although trust in the data was not an issue for F7, they felt the more detailed and location specific projections of My Climate View did not add value beyond their existing expectations of a hotter and drier future: *"As long as those short-term forecasts were accurate, that'd be more beneficial than, say, because everybody knows we're going to get a lot more hotter days in the future" (F7).*

Three farmers (F2, F6 and F16) found the interface did not have their commodity supported in their area, (e.g. avocado's (F16) or specific horticultural varieties (F2, F6). In these instances, not having their commodity supported by the tool appeared to act as a disincentive for future use of My Climate View. A further five farmers (F5, F8, F10, F20, F27) who did not expect to use My Climate View in the future considered the projected changes as beneficial to their operation, for example:

> *"Pumpkin vines, they would wilt a little bit [during extreme heat], but you just put an extra hour of water on them and they revived quite nicely. They didn't mind. The heat on the mangoes just makes them grow harder and faster. So it [projected higher temperatures] is in a way a disguised blessing" (F20)*

Here it appeared perceptions of a similar or favourable future climate may act as a disincentive for future use of multi-decadal climate services, if participants feel that the future climate will not require any changes in their practice for their continued success.

These findings illustrate the multitude of factors affecting the perceived likelihood of use and non-use of My Climate View among farmers, where although trust appears to relate to perceived future use (Figure 2), the reasons for use and non-use extend far beyond trust, and can relate to the individual's personal situation, needs and attitudes. Further, while My Climate View was the interface used to discuss future climate with users, it is clear that responses, particularly around trust, relate to the science of future climate projections more broadly rather than the medium through which they were communicated (My Climate View). Accordingly, as more online climate services become available, future work is necessary to fully understand how trust varies across different interfaces communicating future climate information.

### 5.2. Advisors' trust and expected future use of My Climate View

The distribution of advisors on the trust / expected use matrix (Figure 3) is different to that of farmers, where all but two advisors suggested they would re-visit My Climate View and none mentioned distrusting the projections or data. Ten of the 16 advisors were enthusiastic about My Climate View and discussed ways they might utilise it within their professional advice work.

> *"I loved it. I'd be so interested to know who from the wine sector is using it, like how many people are using it. […] Once I saw it, I was talking to the team here, and I'd really like the team to see the demo as well. And I really want to start pushing it out through our communication channels: 'Hey this thing's available and there's some specific wine metrics in there, you can use it to do XY&Z'" (A1)*

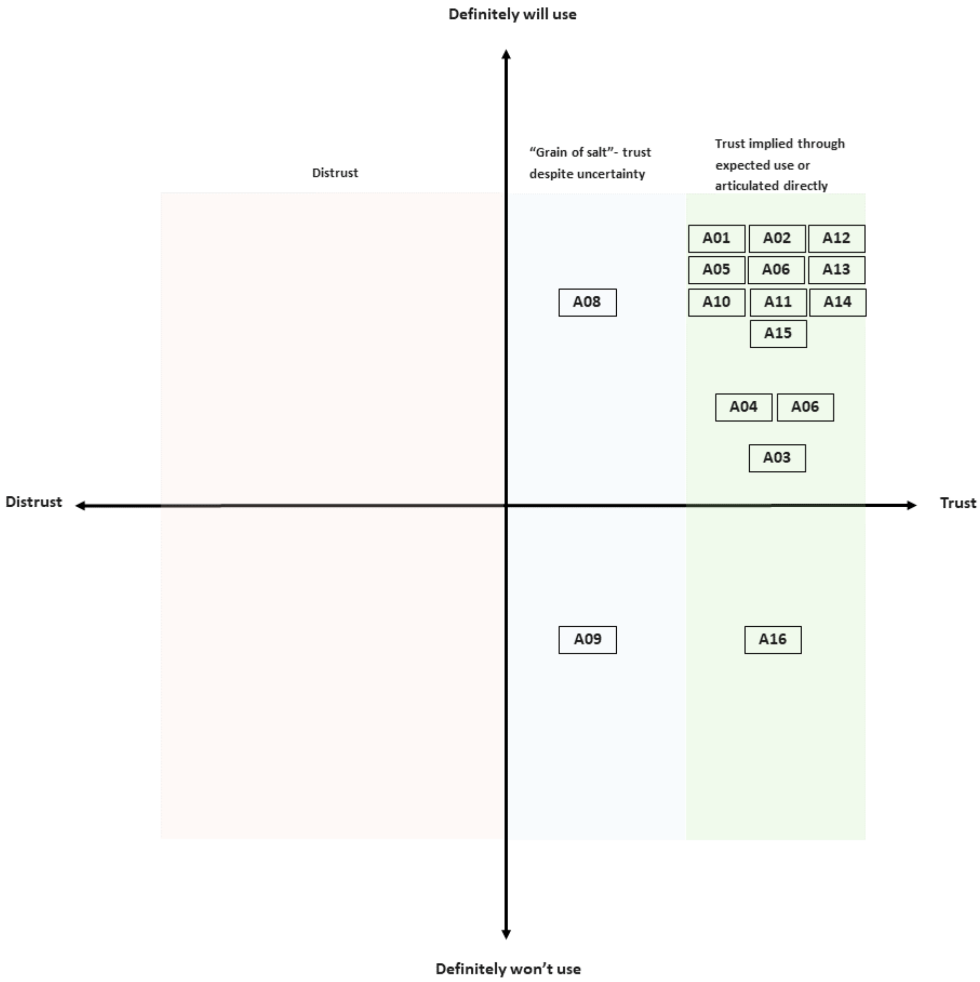


**Figure 3: Advisors plotted according to their trust in My Climate View data (horizontal axis) and expected future use of My Climate View (vertical axis)**

Like farmers, advisors were not asked directly whether they trusted the data and in the majority of interviews trust was implicit in advisors' identification of diverse value from the tool and their enthusiasm to use and to promote through their networks. Unlike the farmer interviews, very few advisors brought up misgivings about the data or source of the projections and interviews instead revolved around potential application areas for the data.

> *"Stumbling across this, I probably relied on it quite a bit, being [developed] from the BoM [Bureau of Meteorology]. Yeah. Sort of came across me at a good time when I was starting to focus in on the climate work. I was doing more soil stuff when I first started [...] And I thought your tool was very helpful in how I am intending to promote technology [to farmers]"* (A13).

> *"I think these maps, particularly these charts where you demonstrate the shifts in rainfall and temperature are pretty useful. […] And you see a step change there in maximum temperatures, that's pretty powerful stuff" (A11)*

A clear feature throughout the advisor interviews was the tendency for advisors to consider My Climate View through the eyes and situations of their clients. While farmers generally considered the metrics according to the potential effect on their own circumstances, advisors' tended to consider the tool from the perspective of their clients. Advisors' thoughts on the interface typically turned towards how it might be useful to their clients, how it might be promoted or scaled to others, and how they might use the tool as part of their work.

*"The first impression is that there's a lot of really interesting medium and longer term data there, and it'll be really great if we linked into the existing support services. [...] This information will be able to really support other services and other services will be able to help the [My Climate View] platform too". (A6)*

Many advisors also described a higher expected frequency of future use of My Climate View than farmers, where their role working with multiple farmers created more opportunities for reference to it: *"I think for an individual client, I don't think they'd probably need to look at it more than sort of once a year quite frankly, but myself, I'll probably use it more often. If I've got people looking at particularly long term decisions I'd probably go through it with them just to refresh what the current situation is" (A4)*

**Non-use:** A9 and A16 were the two advisors who did not expect to use My Climate View. In both these cases, the expected non-use was related to their clients' needs. Both these advisors suggested their clients may not be able to see an actionable use for the information, given the long-term nature of the projections:

*"As an extension officer, these could be some good insights into the future. But as a grazier, I don't really know what decisions there would be that you could make, like we talked about [earlier] in the meeting, unless you're like planting trees or something..." (A9)*

*"I don't know if producers are so much interested in that sort of information. I think what they're more interested in is 'what is happening on my farm that's going to impact my crop over the next five years?' [They feel that] what can I control is what's happening on my farm, and what commodities I'm growing" (A16)*

A3 who is placed closer to the expected use/non-use line explained how they would access the website in the future, but that their engagement would likely reduce when they had gathered the information they needed and did not need to refer to it as often:

*"You'll probably get a lot of that information on the first few times you look, and I have a lot of that information saved already so I don't have to re-access the website. But then again, now I'll probably look back if I see an email saying that, new add-on features or anything like that, similar to other tools" (A03)*

## 6. DISCUSSION

Overall, My Climate View was acknowledged as a valuable tool that many farmers and almost all advisors expected to refer to subsequently. Previous analyses have found My Climate View can assist farmers with conceptualising future risks and reduce psychological distance from climate change [53]. Here our focus is on trust and expected future use, where trust and use are likely prerequisites to action taken against perceived risks. The findings point to several key interactions between users' perceptions of trust and expected future use of My Climate View: (1) Expected future use appears to be mediated by trust but not dependent on trust. (2) Reasons for non-use include, but extend far beyond, trust or distrust of the system. (3) Farmers' circumstances and perceptions are heterogenous and different farmers are likely to require different support to trust, use and benefit from the projections. (4) Advisors represent an important conduit to farmers' engagement with -and potentially trust in- future climate information. HCI literature has dealt extensively with users' trust in technical and autonomous systems [5, 22, 56, 88], but much less so with climate services [70]. The relative absence of climate services as a focus in this field means this paper provides an interesting point of reference to existing HCI work around trust.

**Trust mediates but does not guarantee future use:** Only 7 of the 27 farmers and none of the advisors specifically distrusted the future climate information provided by My Climate View, which is encouraging, given previous literature finds confidence in long-term climate projections among farmers can be mixed [4]. Most of those who expected to use My Climate View again did not express overt distrust over the data, which aligns with extensive literature finding trust is an important precursor to technology acceptance [54, 84] and users' will generally not engage with systems they do not find trustworthy [37, 64]. Yet F3 and F11 are important exceptions here, who expected to revisit My Climate View's future projections again despite distrusting emissions as a driver of future climate. Possible explanations for these perspectives relate to perceived risk of use, and choice [30]. If given a choice, users are less likely to use a system for which they feel usage might carry a risk (e.g. leakage of person details) [89]. Yet simply accessing (as distinct from acting on) My Climate View poses no risk, where F3 is happy to look at it again but *"wouldn't make decisions off it"* (F3). Users may also engage with systems they don't trust when they have little choice, for example the use of unsecured public Wi-Fi hotspots by those who cannot afford other forms of internet [56]. Although a very different context, it is also true that very few geographically-specific multi-decadal climate services exist to date, and future work is necessary to better understand this trust/use relationship when users are presented with multiple choices of geographically-specific future climate information.

**Trust is dynamic and changeable:** Although Figures 2 and 3 represent point-in-time snapshots of trust and expected future use, our findings underscore the dynamic and changeable nature of users' trust in technical systems [18]. F3 and F11's intention to continue to use My Climate View despite distrusting the data hints at an openness to their trust in the system increasing in the future. Similarly, participants whose commodities were not supported by the tool (at the time of the interview) may be encouraged to use the tool in the future if/when their commodities are supported. Given engagement in technology and trust are precursors to sustainable behaviour change [9, 33], it is important to consider avenues of influence for trust and engagement in My Climate View. A role for HCI here is leveraging opportunities to shift participants further to the top-right of the trust/distrust axes of Figures 2 and 3. Given the heterogeneity of farmers' circumstances and the diversity of factors that affect trust and use, we argue that design approaches that favour more linear cause-effect relationships between technology and action, such as persuasive design, may be limiting in this space [11]. Rather, trust may be achieved via a sustained focus on user needs and keeping users (and other stakeholders) involved throughout future iterations of climate services development [24]. These are already well proven capabilities HCI [5, 9, 32].

**The role of advisors as a conduit to trust and engagement:** Agricultural systems literature points to the importance of supporting complex decisions rather than changing specific behaviours [45] and it recognises advisors as trusted "brokers" of information in agriculture [43]. Advisors in our study overwhelmingly trusted My Climate View and given their influence on farming decisions across multiple time scales [31, 43], may be influential in engendering use and trust among farmers. This role might involve mediating climate information from technology to farmers, meaning that farmers don't need to "adopt" the technology themselves [47]. This is particularly important with respect to multi-decadal climate services, which advisors might use regularly due to their interacting with multiple farmers, yet individual farmers themselves are unlikely to engage with as frequently; as F27 states: "*There's not enough that's potentially going to change for me to want me to come back and look at it in six months' time" (F27)*.

Accordingly, like others, we argue climate services must be designed to accommodate both advisors and support advisor-farmer engagements [23]. The range of farmers' perceptions on My Climate View are highlighted in Figure 2 and hence a key challenge is how advisors might best build trust and support use despite farmers' diverse perspectives and circumstances. In Figure 4 below we provide suggestions:

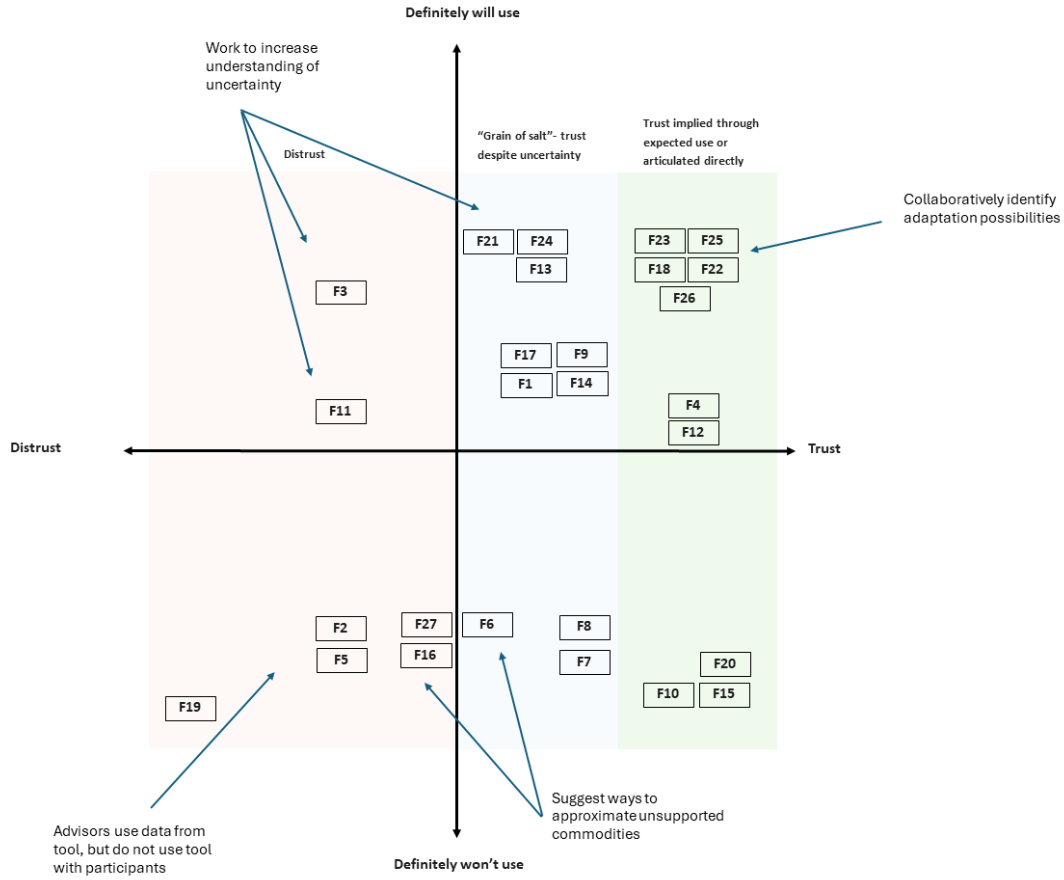


**Figure 4: Suggestions for supporting farmers' heterogenous circumstances: Arrows list possible ways advisors might incorporate climate projections in their work with different groups of farmers in a way that caters for which cater for their varying levels of trust in climate information.**

For farmers in the top right quadrant (Figure 4) who already identify and pursue use cases for My Climate View, advisors may seek to extend these existing use cases by collaboratively identifying adaptation possibilities with farmers, i.e. supporting the transition from information to action. For farmers in the bottom-left quadrant with an active distrust in long-term climate projections, it might be more appropriate for advisors to incorporate the projections in their own suggestions, rather than directing farmers to use the tool themselves. Studies highlight the benefits of de-coupling discussions of anthropogenic climate change from discussions of forward planning, investment and resilience/adaptation, where successful implementation of climate adaptation actions does not require alignment with climate change beliefs [65]. For participants who are more cautious about the projections (blue column, Figure 4), supporting future use might involve building and "calibrating" participants' trust of the projections (described below). For those farmers' whose commodities were not supported (F2, F6, F16), advisors could suggest ways to approximate their commodity (e.g. adjusting parameters on supported commodities to provide comparable information for more niche unsupported commodities), which the tool allows. We also acknowledge there are circumstances where it may not be productive to engage with long-term climate services, such as F15 and F20 who are seeking to exit agriculture, and for whom commodity-specific climate projections may simply not be relevant.

### 6.1. How HCI might engage with climate services

Based on our findings, we outline two research avenues for which the field of HCI might productively support climate services development and implementation. These two specific examples build on the more general areas of HCI expertise that Rigby & Priest [70] outline as beneficial to climate services development.

**Calibrating trust**: "Calibrating" trust refers to closing the gap between users' trust in a technology and the system's actual capabilities [22]. Because many farmers were unfamiliar with multi-decadal climate services, it is understandable that several participants' trust in My Climate View's projections were based on arbitrary factors such as personal experiences and gut feel as much as the scientific uncertainty of the projections themselves. For example, the hit-and-miss nature of wet season rainfall in the Northern Territory (F13) or prior disappointments with weather forecasting (F1). The same situation is found throughout HCI studies of trust in autonomous systems, where users' trust in (new) technical systems is unavoidably formed with imperfect knowledge of that system [64]. Hence achieving greater acceptance of these technologies involves (in part) a process of "calibrating" trust; better aligning users' expectations with actual system capabilities [22]. For autonomous vehicles, an external indication of system state and intent was found to facilitate a trust level among pedestrians that was much more in line with the actual capabilities and error rate of the autonomous vehicle [22]. In the case of climate services, we argue that design attention is necessary to adequately communicate the inherent uncertainties of multi-decadal climate projections. One means of doing so may be to communicate climate projections as ranges rather than averages where possible. Ranges may better communicate the model's higher confidence in an outcome falling within a given range, where averages which may be interpreted as a definitive value and potentially reduce trust. Another means of calibrating trust in climates services may be to communicate past model performance, i.e. to assist in setting expectations for possible future performance. Design efforts to calibrate trust may be beneficial both to those already circumspect about the projections (light blue panel, Figure 3), but equally those who already trust My Climate View (green panel), where it is also necessary to ensure that participants already using the projections are interpreting them within their appropriate uncertainties.

**From "adoption" metrics to user engagement:** "Adoption" is a widely used term within agricultural literature, relating to continued use of a given practice or technology [26]. Yet in the same way that linear theories of behaviour change negate the complex relationship between sustainability and human behaviour [11], "adoption" is increasingly recognised as a binary term which is insufficient to explain users' often more complex interactions with technology [60]. Similarly, "adoption" itself is not an ideal term for farmers' interaction with multi-decadal climate services which they may not consult on a regular basis. Instead, metrics used by HCI authors to understand engagement with personal informatics could be explored in relation to climate services. Reflections on both personal informatics [40] and household-scale informatics [75] consist of an oscillation between the Discovery Phase (exploration, fact-finding, knowledge building) and Maintenance Phase (checking things are tracking as expected [40]. In this present study we have engaged with farmers during the Discovery Phase, gathering first impressions of usefulness and use, yet subsequent follow-up work will be necessary to understand the Maintenance Phase, e.g. when and for what purpose do farmers re-visit My Climate View on their own accord? What information are they seeking on subsequent visits relative to their first? Compared to eco-feedback dashboards which may update hourly or daily, HCI might usefully engage with exploring the manifestations of Discovery and Maintenance Phases of farmers' engagement of multi-decadal climate services and how best to cater for both.

### 6.2. Limitations

The findings are derived from conversations around one multi-decadal climate services tool. This is reasonable, given few of these tools exist to date. But future work would be helpful to understand perceptions of different multi-decadal interfaces and to understand the extent to which concerns over the future climate data are concerns with the climate science behind the future projections, or with the tool itself (e.g. My Climate View). We expect that due to My Climate View being participants' first experience of future projections, that concerns over the data related to the perceived accuracy of future climate projections generally, rather than My Climate View itself, but future work is necessary. The placement of participants across the trust/use spectrums of Figures 2 and 3 is indicative only and is not an attempt to quantitatively measure these factors. The sample is representative of farmers and advisors growing and advising across several commodities and geographies, but further work is needed to determine the generalisability of these findings internationally, given our farmer participants all owned a smart phone and all but one were comfortable accessing information on the internet independently. Future work would also be helpful with larger cohorts from specific industries to better understand differences between grower types (e.g. broadacre versus beef versus viticulture).

## 7. CONCLUSION

Climate services are an important conduit to agricultural adaptation in Australia and elsewhere. This paper has contributed new knowledge regarding the relationship between trust and expected future use of multi-decadal climate services. In doing so, we have identified how design work might best support farmers' individual circumstances, rather than attempting to persuade behaviour, and the important role of advisors in building trust and legitimacy of climate services. Further, answering a specific call by Rigby & Priest [70], we provide a case study of how HCI can usefully engage in climate services, in areas such as calibrating trust and providing alternative lenses and metrics to evaluate user engagement. The urgency of climate action and the clear fit of HCI expertise in this space leads us to call for further cross disciplinary research and collaboration in this space.

## ACKNOWLEDGEMENTS

We are indebted to the participants for their generosity of time and insights. Thank you to Farmlink and Sarah Clarry for assistance with sampling for the study. Particular thanks must go to the CSIRO Climate Services for Agriculture (CSA) Social Science Team: Aysha Fleming, Emma Jakku, Yuwan Malakar and Simon Fielke whose perspectives and data have contributed immensely to the preparation of this paper. Thanks to the broader CSA team consisting of representatives from CSIRO, Data 61 and the Bureau of Meteorology. This work has benefited from the CSIRO Impossible Without You program.

## REFERENCES


[1] I. Aguirre-Bielschowsky, R. Lawson, J. Stephenson, and S. Todd. 2017. Energy literacy and agency of New Zealand children. *Environmental Education Research* 23, 5 (2017), 832–854. https://doi.org/10.1080/13504622.2015.1054267

[2] Ferran Altarriba Bertran, Samvid Jhaveri, Rosa Lutz, Katherine Isbister, and Danielle Wilde. 2019. Making Sense of Human-Food Interaction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, May 02, 2019. ACM, Glasgow Scotland Uk, 1–13. https://doi.org/10.1145/3290605.3300908

[3] Philip Antwi-Agyei, Emmanuel Mawuli Abalo, Andrew John Dougill, and Frank Baffour-Ata. 2021. Motivations, enablers and barriers to the adoption of climate-smart agricultural practices by smallholder farmers: Evidence from the transitional and savannah agroecological zones of Ghana. *Regional Sustainability* 2, 4 (2021), 375–386. https://doi.org/10.1016/j.regsus.2022.01.005

[4] J. Gordon Arbuckle, Lois Wright Morton, and Jon Hobbs. 2015. Understanding Farmer Perspectives on Climate Change Adaptation and Mitigation: The Roles of Trust in Sources of Climate Information, Climate Change Beliefs, and Perceived Risk. *Environment and Behavior* 47, 2 (February 2015), 205–234. https://doi.org/10.1177/0013916513503832

[5] Tita Alissa Bach, Amna Khan, Harry Hallock, Gabriela Beltrão, and Sonia Sousa. 2024. A Systematic Literature Review of User Trust in AI-Enabled Systems: An HCI Perspective. *International Journal of Human–Computer Interaction* 40, 5 (March 2024), 1251–1266. https://doi.org/10.1080/10447318.2022.2138826

[6] Lyn Bartram. 2015. Design Challenges and Opportunities for Eco-Feedback in the Home. *IEEE Comput. Grap. Appl.* 35, 4 (July 2015), 52–62. https://doi.org/10.1109/MCG.2015.69

[7] Ann Blandford. 2019. HCI for health and wellbeing: Challenges and opportunities. *International Journal of Human-Computer Studies* 131, (November 2019), 41–51. https://doi.org/10.1016/j.ijhcs.2019.06.007

[8] Virginia Braun and Victoria Clarke. 2022. *Thematic analysis: a practical guide*. SAGE, Los Angeles.

[9] Christina Bremer, Bran Knowles, and Adrian Friday. 2022. Have We Taken On Too Much?: A Critical Review of the Sustainable HCI Landscape. In *CHI Conference on Human Factors in Computing Systems*, April 27, 2022. ACM, New Orleans LA USA, 1–11. https://doi.org/10.1145/3491102.3517609

[10] Barry Brown, Fanjun Bu, Ilan Mandel, and Wendy Ju. 2024. Trash in Motion: Emergent Interactions with a Robotic Trashcan. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, May 11, 2024. ACM, Honolulu HI USA, 1–17. https://doi.org/10.1145/3613904.3642610

[11] Hronn Brynjarsdottir, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. Sustainably unpersuaded. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*, 2012. 947–947. https://doi.org/10.1145/2207676.2208539

[12] Hyesun Choung, Prabu David, and Arun Ross. 2023. Trust in AI and Its Role in the Acceptance of AI Technologies. *International Journal of Human–Computer Interaction* 39, 9 (May 2023), 1727–1739. https://doi.org/10.1080/10447318.2022.2050543

[13] CSIRO and Bureau of Meteorology. 2023. My Climate View. Retrieved April 2, 2023 from My Climate View

[14] Colette Cuijpers and Bert-Jaap Koops. 2013. Smart Metering and Privacy in Europe: Lessons from the Dutch Case. In *European Data Protection: Coming of Age*, Serge Gutwirth, Ronald Leenes, Paul De Hert and Yves Poullet (eds.). Springer Netherlands, Dordrecht, 269–293. https://doi.org/10.1007/978-94-007-5170-5_12

[15] Riccardo Dainelli, Sandro Calmanti, Massimiliano Pasqui, Leandro Rocchi, Edmondo Di Giuseppe, Chiara Monotti, Sara Quaresima, Alessandro Matese, Salvatore Filippo Di Gennaro, and Piero Toscano. 2022. Moving

climate seasonal forecasts information from useful to usable for early within-season predictions of durum wheat yield. *Climate Services* 28, (December 2022), 100324. https://doi.org/10.1016/j.cliser.2022.100324
[16] Tawanna R. Dillahunt, Sylvia Simioni, and Xuecong Xu. 2019. Online Grocery Delivery Services: An Opportunity to Address Food Disparities in Transportation-Scarce Areas. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (*CHI '19*), 2019. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3290605.3300879
[17] Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. Mapping the landscape of sustainable HCI. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, 2010. ACM Press, Atlanta, Georgia, USA, 1975. https://doi.org/10.1145/1753326.1753625
[18] Olivia Doggett, Kelly Bronson, and Robert Soden. 2023. HCI Research on Agriculture: Competing Sociotechnical Imaginaries, Definitions, and Opportunities. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, April 19, 2023. ACM, Hamburg Germany, 1–24. https://doi.org/10.1145/3544548.3581081
[19] Francis R. Eanes, Ajay S. Singh, Brian R. Bulla, Pranay Ranjan, Mary Fales, Benjamin Wickerham, Patrick J. Doran, and Linda S. Prokopy. 2019. 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, (February 2019), 360–370. https://doi.org/10.1016/j.landusepol.2018.10.054
[20] Sheena Erete, Aarti Israni, and Tawanna Dillahunt. 2018. An intersectional approach to designing in the margins. *interactions* 25, 3 (April 2018), 66–69. https://doi.org/10.1145/3194349
[21] Siri H. Eriksen, Andrea J. Nightingale, and Hallie Eakin. 2015. Reframing adaptation: The political nature of climate change adaptation. *Global Environmental Change* 35, (November 2015), 523–533. https://doi.org/10.1016/j.gloenvcha.2015.09.014
[22] Stefanie Faas, Johannes Kraus, Alexander Schoenhals, and Martin Baumann. 2021. Calibrating Pedestrians' Trust in Automated Vehicles: Does an Intent Display in an External HMI Support Trust Calibration and Safe Crossing Behavior? In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, May 06, 2021. ACM, Yokohama Japan, 1–17. https://doi.org/10.1145/3411764.3445738
[23] Kieran Findlater, Sophie Webber, Milind Kandlikar, and Simon Donner. 2021. Climate services promise better decisions but mainly focus on better data. *Nat. Clim. Chang.* 11, 9 (September 2021), 731–737. https://doi.org/10.1038/s41558-021-01125-3
[24] Jon Froehlich, Leah Findlater, and James Landay. 2010. The design of eco-feedback technology. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, 2010. 1999–1999. https://doi.org/10.1145/1753326.1753629
[25] Jon Froehlich, Shwetak Patel, James A. Landay, Leah Findlater, Marilyn Ostergren, Solai Ramanathan, Josh Peterson, Inness Wragg, Eric Larson, Fabia Fu, and Mazhengmin Bai. 2012. The design and evaluation of prototype eco-feedback displays for fixture-level water usage data. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*, 2012. 2367–2367. https://doi.org/10.1145/2207676.2208397
[26] Carlo Giua, Valentina Cristiana Materia, and Luca Camanzi. 2022. Smart farming technologies adoption: Which factors play a role in the digital transition? *Technology in Society* 68, (2022), 101869. https://doi.org/10.1016/j.techsoc.2022.101869
[27] Dominic Glover, James Sumberg, Giel Ton, Jens Andersson, and Lone Badstue. 2019. Rethinking technological change in smallholder agriculture. *Outlook Agric* 48, 3 (September 2019), 169–180. https://doi.org/10.1177/0030727019864978
[28] Theodore Grantham, Faith Kearns, Susie Kocher, Leslie Roche, and Tapan Pathak. 2017. Building climate change resilience in California through UC Cooperative Extension. *Calif Agr* 71, 4 (November 2017), 197–200. https://doi.org/10.3733/ca.2017a0045
[29] Sophie Grimme, Susanna Marie Spoerl, Susanne Boll, and Marion Koelle. 2024. My Data, My Choice, My Insights: Women's Requirements when Collecting, Interpreting and Sharing their Personal Health Data. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, May 11, 2024. ACM, Honolulu HI USA, 1–18. https://doi.org/10.1145/3613904.3642851
[30] Siddharth Gulati, Sonia Sousa, and David Lamas. 2019. Design, development and evaluation of a human-computer trust scale. *Behaviour & Information Technology* 38, 10 (October 2019), 1004–1015. https://doi.org/10.1080/0144929X.2019.1656779
[31] Tonya Haigh, Lois Wright Morton, Maria Carmen Lemos, Cody Knutson, Linda Stalker Prokopy, Yun Jia Lo, and Jim Angel. 2015. Agricultural Advisors as Climate Information Intermediaries: Exploring Differences in Capacity to Communicate Climate. *Weather, Climate, and Society* 7, 1 (January 2015), 83–93. https://doi.org/10.1175/WCAS-D-14-00015.1
[32] Jean Hardy, Susan Wyche, and Tiffany Veinot. 2019. Rural HCI Research: Definitions, Distinctions, Methods, and Opportunities. *Proc. ACM Hum.-Comput. Interact.* 3, CSCW (November 2019), 1–33. https://doi.org/10.1145/3359298
[33] Björn Hedin, Cecilia Katzeff, Elina Eriksson, and Daniel Pargman. 2019. A Systematic Review of Digital Behaviour Change Interventions for More Sustainable Food Consumption. *Sustainability* 11, 9 (May 2019), 2638. https://doi.org/10.3390/su11092638

[34] Vaughan Higgins, Melanie Bryant, Andrea Howell, and Jane Battersby. 2017. Ordering adoption: Materiality, knowledge and farmer engagement with precision agriculture technologies. *Journal of Rural Studies* 55, (October 2017), 193–202. https://doi.org/10.1016/j.jrurstud.2017.08.011

[35] Md. Rakibul Hoque. 2020. The impact of the ICT4D project on sustainable rural development using a capability approach: Evidence from Bangladesh. *Technology in Society* 61, (May 2020), 101254. https://doi.org/10.1016/j.techsoc.2020.101254

[36] IPSOS. 2022. The IPSOS Climate Change Report. Retrieved September 22, 2022 from https://www.ipsos.com/sites/default/files/ct/publication/documents/2022-04/Ipsos%20Climate%20Change%20Report%202022.pdf

[37] Emma Jakku, Bruce Taylor, Aysha Fleming, Claire Mason, Simon Fielke, Chris Sounness, and Peter Thorburn. 2019. "If they don't tell us what they do with it, why would we trust them?" Trust, transparency and benefit-sharing in Smart Farming. *NJAS - Wageningen Journal of Life Sciences* 90–91, (2019), 100285. https://doi.org/10.1016/j.njas.2018.11.002

[38] S. Mo Jang and P. Sol Hart. 2015. Polarized frames on "climate change" and "global warming" across countries and states: Evidence from Twitter big data. *Global Environmental Change* 32, (May 2015), 11–17. https://doi.org/10.1016/j.gloenvcha.2015.02.010

[39] Rikke Hagensby Jensen, Maurizio Teli, Simon Bjerre Jensen, Mikkel Gram, and Mikkel Harboe Sørensen. 2021. Designing Eco-Feedback Systems for Communities: Interrogating a Techno-solutionist Vision for Sustainable Communal Energy. In *C&T '21: Proceedings of the 10th International Conference on Communities & Technologies - Wicked Problems in the Age of Tech*, June 20, 2021. ACM, Seattle WA USA, 245–257. https://doi.org/10.1145/3461564.3461581

[40] Elisabeth T. Kersten-van Dijk, Joyce H.D.M. Westerink, Femke Beute, and Wijnand A. IJsselsteijn. 2017. Personal Informatics, Self-Insight, and Behavior Change: A Critical Review of Current Literature. *Human–Computer Interaction* 32, 5–6 (November 2017), 268–296. https://doi.org/10.1080/07370024.2016.1276456

[41] Sunyoung Kim and Muyang Li. 2020. Awareness, Understanding, and Action: A Conceptual Framework of User Experiences and Expectations about Indoor Air Quality Visualizations. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, April 21, 2020. ACM, Honolulu HI USA, 1–12. https://doi.org/10.1145/3313831.3376521

[42] Sunyoung Kim, Eric Paulos, and Jennifer Mankoff. 2013. inAir: A Longitudinal Study of Indoor Air Quality Measurements and Visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2013. Paris, France, 2745–2754. https://doi.org/10.1145/2470654.2481380

[43] Laurens Klerkx and Cees Leeuwis. 2009. Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technological Forecasting and Social Change* 76, 6 (July 2009), 849–860. https://doi.org/10.1016/j.techfore.2008.10.001

[44] Utku Kose, V. B. Surya Prasath, M. Rubaiyat Hossain Mondal, Prajoy Podder, and Subrato Bharati. 2022. *Artificial Intelligence and Smart Agriculture Technology* (1st ed.). Auerbach Publications, New York. https://doi.org/10.1201/9781003299059

[45] R Kröbel, E C Stephens, M A Gorzelak, M-N Thivierge, F Akhter, J Nyiraneza, S D Singer, C M Geddes, A J Glenn, N Devillers, A W Alemu, M St. Luce, and D Giardetti. 2021. Making farming more sustainable by helping farmers to decide rather than telling them what to do. *Environ. Res. Lett.* 16, 5 (May 2021), 055033. https://doi.org/10.1088/1748-9326/abef30

[46] Hyosun Kwon, Joel E. Fischer, Martin Flintham, and James Colley. 2018. The Connected Shower: Studying Intimate Data in Everyday Life. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 4 (December 2018), 1–22. https://doi.org/10.1145/3287054

[47] Maria Carmen Lemos, Yun-Jia Lo, Christine Kirchhoff, and Tonya Haigh. 2014. Crop advisors as climate information brokers: Building the capacity of US farmers to adapt to climate change. *Climate Risk Management* 4–5, (2014), 32–42. https://doi.org/10.1016/j.crm.2014.08.001

[48] Joseph Lindley, Paul Coulton, and Miriam Sturdee. 2017. Implications for Adoption. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, May 02, 2017. ACM, Denver Colorado USA, 265–277. https://doi.org/10.1145/3025453.3025742

[49] Junyu Lu, Maria Carmen Lemos, Vikram Koundinya, and Linda S. Prokopy. 2021. Scaling up co-produced climate-driven decision support tools for agriculture. *Nat Sustain* 5, 3 (December 2021), 254–262. https://doi.org/10.1038/s41893-021-00825-0

[50] E. Luger, T. Rodden, M. Jirotka, and L. Edwards. 2014. How do you solve a problem like consent?: the workshop. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*, 2014. ACM, Seattle, 613–619. https://doi.org/10.1145/2638728.2641676

[51] Peter Lyle, Jaz Hee-jeong Choi, and Marcus Foth. 2015. Growing food in the city: design ideations for urban residential gardeners. In *Proceedings of the 7th International Conference on Communities and Technologies*, June 27, 2015. ACM, Limerick Ireland, 89–97. https://doi.org/10.1145/2768545.2768549

[52] Guofeng Ma, Jing Lin, and Nan Li. 2018. Longitudinal assessment of the behavior-changing effect of app-based eco-feedback in residential buildings. *Energy and Buildings 159*, 486–494. https://doi.org/10.1016/j.enbuild.2017.11.019

[53] Yuwan Malakar, Stephen Snow, Aysha Fleming, Simon Fielke, Emma Jakku, Carly Tozer, and Rebecca Darbyshire. 2024. Multi-decadal climate services help farmers assess and manage future risks. *Nat. Clim. Chang.* 14, 6 (June 2024), 586–591. https://doi.org/10.1038/s41558-024-02021-2

[54] Elizabeth D. Matemba, Guoxin Li, Ives Chacourre Wangninanon Gogan, and Baraka J. Maiseli. 2020. Technology acceptance model: recent developments, future directions, and proposal for hypothetical extensions. *IJTIP* 12, 4 (2020), 315. https://doi.org/10.1504/IJTIP.2020.109769
[55] Akhil Mathur, Marc Van Den Broeck, Geert Vanderhulst, Afra Mashhadi, Fahim Kawsar, and Bell Laboratories. 2015. Tiny Habits in the Giant Enterprise : Understanding the Dynamics of a Quantified Workplace. *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)* (2015), 577–588.
[56] Nora McDonald and Andrea Forte. 2020. The Politics of Privacy Theories: Moving from Norms to Vulnerabilities. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, April 21, 2020. ACM, Honolulu HI USA, 1–14. https://doi.org/10.1145/3313831.3376167
[57] Brian James McInnis, Ramona Pindus, Daniah Kareem, Savannah Gamboa, and Camille Nebeker. 2024. Exploring the Future of Informed Consent: Applying a Service Design Approach. *Proc. ACM Hum.-Comput. Interact.* 8, CSCW1 (April 2024), 1–31. https://doi.org/10.1145/3637330
[58] Jochen Meyer, Steven Simske, Katie A. Siek, Cathal G. Gurrin, and Hermie Hermens. 2014. Beyond quantified self: data for wellbeing. In *Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems - CHI EA '14*, 2014. ACM Press, Toronto, Ontario, Canada, 95–98. https://doi.org/10.1145/2559206.2560469
[59] Mokhele E. Moeletsi and Mitsuru Tsubo. 2024. A Move towards Developing Usable Climate Change Adaptation and Mitigation Services for the Agricultural Sector. *Climate* 12, 3 (March 2024), 46. https://doi.org/10.3390/cli12030046
[60] Oscar Montes De Oca Munguia, David J. Pannell, Rick Llewellyn, and Philip Stahlmann-Brown. 2021. Adoption pathway analysis: Representing the dynamics and diversity of adoption for agricultural practices. *Agricultural Systems* 191, (June 2021), 103173. https://doi.org/10.1016/j.agsy.2021.103173
[61] Eliana Mozo-Reyes, Jenna R. Jambeck, Patricia Reeves, and Kyle Johnsen. 2016. Will they recycle? Design and implementation of eco-feedback technology to promote on-the-go recycling in a university environment. *Resources, Conservation and Recycling* 114, (November 2016), 72–79. https://doi.org/10.1016/j.resconrec.2016.06.024
[62] Florian 'Floyd' Mueller, Marianna Obrist, Ferran Altarriba Bertran, Neharika Makam, Soh Kim, Christopher Dawes, Patrizia Marti, Maurizio Mancini, Eleonora Ceccaldi, Nandini Pasumarthy, Sahej Claire, Kyung Seo Jung, Jialin Deng, Jürgen Steimle, Nadejda Krasteva, Matti Schwalk, Harald Reiterer, Hongyue Wang, and Yan Wang. 2024. Grand challenges in human-food interaction. *International Journal of Human-Computer Studies* 183, (March 2024), 103197. https://doi.org/10.1016/j.ijhcs.2023.103197
[63] Michael O'Grady, David Langton, Francesca Salinari, Peter Daly, and Gregory O'Hare. 2021. Service design for climate-smart agriculture. *Information Processing in Agriculture* 8, 2 (2021), 328–340. https://doi.org/10.1016/j.inpa.2020.07.003
[64] Andrea Papenmeier, Dagmar Kern, Gwenn Englebienne, and Christin Seifert. 2022. It's Complicated: The Relationship between User Trust, Model Accuracy and Explanations in AI. *ACM Trans. Comput.-Hum. Interact.* 29, 4 (August 2022), 1–33. https://doi.org/10.1145/3495013
[65] Margiana Petersen-Rockney. 2022. Social risk perceptions of climate change: A case study of farmers and agricultural advisors in northern California. *Global Environmental Change* 75, (July 2022), 102557. https://doi.org/10.1016/j.gloenvcha.2022.102557
[66] Linda Stalker Prokopy, J. Stuart Carlton, Tonya Haigh, Maria Carmen Lemos, Amber Saylor Mase, and Melissa Widhalm. 2017. Useful to Usable: Developing usable climate science for agriculture. *Climate Risk Management* 15, (2017), 1–7. https://doi.org/10.1016/j.crm.2016.10.004
[67] Linda Stalker Prokopy, Tonya Haigh, Amber Saylor Mase, Jim Angel, Chad Hart, Cody Knutson, Maria Carmen Lemos, Yun-Jia Lo, Jean McGuire, Lois Wright Morton, Jennifer Perron, Dennis Todey, and Melissa Widhalm. 2013. Agricultural Advisors: A Receptive Audience for Weather and Climate Information? *Weather, Climate, and Society* 5, 2 (April 2013), 162–167. https://doi.org/10.1175/WCAS-D-12-00036.1
[68] Amon Rapp, Federica Cena, Judy Kay, Bob Kummerfeld, Frank Hopfgartner, Till Plumbaum, Jakob Eg Larsen, Daniel A. Epstein, and Rúben Gouveia. 2016. New frontiers of quantified self 2: going beyond numbers. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, September 12, 2016. ACM, Heidelberg Germany, 506–509. https://doi.org/10.1145/2968219.2968331
[69] F. Redhead, S. Snow, D. Vyas, O. Bawden, R. Russell, T. Perez, and M. Brereton. 2015. Bringing the farmer perspective to agricultural robots. In *Conference on Human Factors in Computing Systems - Proceedings*, 2015. . https://doi.org/10.1145/2702613.2732894
[70] Jacob M Rigby and Chris Preist. 2023. Towards User-Centred Climate Services: the Role of Human-Computer Interaction. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, April 19, 2023. ACM, Hamburg Germany, 1–14. https://doi.org/10.1145/3544548.3580663
[71] P Rigger, F Wortmann, and A Dahlinger. 2015. Design Science in Practice: Design and Evaluation of an Art Based Information System to Improve Indoor Air Quality at Schools. In *International Conference on Design Science Research in Information Systems*, 2015. Springer International Publishing, Dublin, Ireland, 71–86. https://doi.org/10.1007/978-3-319-18714-3_5
[72] Michael Robertson and Roy Murray-Prior. 2016. 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, 1 (January 2016), 189–198. https://doi.org/10.1007/s10113-014-0743-4
[73] Everett Rogers. 2003. *Diffusion of Innovation* (Fifth ed.). Free Press, New York.

[74] m.c. schraefel. 2019. in5: a Model for Inbodied Interaction. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, May 02, 2019. ACM, Glasgow Scotland Uk, 1–6. https://doi.org/10.1145/3290607.3312977
[75] S. Snow, L. Buys, P. Roe, and M. Brereton. 2013. Curiosity to cupboard- self reported disengagement with energy use feedback over time. In *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration, OzCHI 2013*, 2013. . https://doi.org/10.1145/2541016.2541025
[76] Stephen Snow, Aysha Fleming, Simon Fielke, Yuwan Malakar, Emma Jakku, Carly Tozer, and Graham D Bonnett. 2024. "A little bit obsessed with the weather": Leveraging Australian farmers' online weather practices to inform the design of climate services. *NJAS: Impact in Agricultural and Life Sciences* 96, 1 (December 2024), 2296652. https://doi.org/10.1080/27685241.2023.2296652
[77] Stephen Snow, Dhaval Vyas, and Margot Brereton. 2015. When an eco-feedback system joins the family. *Personal and Ubiquitous Computing 19*, 929–940. https://doi.org/10.1007/s00779-015-0839-y
[78] Cara A. Stitzlein and Martijn Mooij. 2019. Design for Discovery: Helping Australian Farmers Explore their Options in a Government Sustainability Program Through User Centred Design. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 63, 1 (November 2019), 1173–1177. https://doi.org/10.1177/1071181319631312
[79] Cara Stitzlein, Jeffrey A. Baldock, Stephen H. Roxburgh, Martijn Mooij, Daniel Smith, and Peter Fitch. 2023. Facilitating entry to land sector carbon abatement projects: the LOOC-C tool. *Carbon Management* 14, 1 (December 2023), 2265156. https://doi.org/10.1080/17583004.2023.2265156
[80] Eugene S. Takle, Christopher J. Anderson, Jeffrey Andresen, James Angel, Roger W. Elmore, Benjamin M. Gramig, Patrick Guinan, Steven Hilberg, Doug Kluck, Raymond Massey, Dev Niyogi, Jeanne M. Schneider, Martha D. Shulski, Dennis Todey, and Melissa Widhalm. 2014. Climate Forecasts for Corn Producer Decision Making. *Earth Interactions* 18, 5 (March 2014), 1–8. https://doi.org/10.1175/2013EI000541.1
[81] United Nations. 2024. Climate Change Adaptation. Retrieved March 3, 2024 from https://www.un.org/en/climatechange/climate-adaptation
[82] Catherine Vaughan, Suraje Dessai, and Chris Hewitt. 2018. Surveying Climate Services: What Can We Learn from a Bird's-Eye View? *Weather, Climate, and Society* 10, 2 (April 2018), 373–395. https://doi.org/10.1175/WCAS-D-17-0030.1
[83] Katharine Vincent, Meaghan Daly, Claire Scannell, and Bill Leathes. 2018. What can climate services learn from theory and practice of co-production? *Climate Services* 12, (December 2018), 48–58. https://doi.org/10.1016/j.cliser.2018.11.001
[84] E. S. Vorm and David J. Y. Combs. 2022. Integrating Transparency, Trust, and Acceptance: The Intelligent Systems Technology Acceptance Model (ISTAM). *International Journal of Human–Computer Interaction* 38, 18–20 (December 2022), 1828–1845. https://doi.org/10.1080/10447318.2022.2070107
[85] Geoff Walsham. 2017. ICT4D research: reflections on history and future agenda. *Information Technology for Development* 23, 1 (January 2017), 18–41. https://doi.org/10.1080/02681102.2016.1246406
[86] Leanne Webb, Carly Tozer, Lynette Bettio, Rebecca Darbyshire, Bella Robinson, Aysha Fleming, Sigrid Tijs, Roger Bodman, and Mahesh Prakash. 2023. Climate Services for Agriculture: Tools for Informing Decisions Relating to Climate Change and Climate Variability in the Wine Industry. *Australian Journal of Grape and Wine Research* 2023, (April 2023), 1–13. https://doi.org/10.1155/2023/5025359
[87] Rosaine N. Yegbemey and Janvier Egah. 2021. Reaching out to smallholder farmers in developing countries with climate services: A literature review of current information delivery channels. *Climate Services* 23, (August 2021), 100253. https://doi.org/10.1016/j.cliser.2021.100253
[88] Ming Yin, Jennifer Wortman Vaughan, and Hanna Wallach. 2019. Understanding the Effect of Accuracy on Trust in Machine Learning Models. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, May 02, 2019. ACM, Glasgow Scotland Uk, 1–12. https://doi.org/10.1145/3290605.3300509
[89] Kun Yu, Shlomo Berkovsky, Ronnie Taib, Dan Conway, Jianlong Zhou, and Fang Chen. 2017. User Trust Dynamics: An Investigation Driven by Differences in System Performance. In *Proceedings of the 22nd International Conference on Intelligent User Interfaces*, March 07, 2017. ACM, Limassol Cyprus, 307–317. https://doi.org/10.1145/3025171.3025219