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Energy audits and eco-feedback: Exploring the barriers and facilitators of agricultural energy efficiency improvements on Australian farms

Stephen Snow [a,*], Carolina Clerc [b,c], Neil Horrocks [a]

[a] Centre for Energy Data Innovation, School of IT and Electronic Engineering, The University of Queensland, Australia
[b] School of Chemical Engineering, The University of Queensland, Australia
[c] Queensland Farmers Federation, Australia

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ABSTRACT

This paper aims to understand the farm-level barriers and opportunities to greater energy efficiency in the Australian agricultural sector. Using a mixed methods approach informed by social practice theory, we detail the experiences of 12 farmers who received an energy audit and energy use feedback dashboard (eco-feedback) through government-supported energy efficiency initiatives. Findings suggest on-farm energy use is dictated by a number of heterogeneous factors and practices, where despite an overall positive reception to the interventions, a lack of available time, funds, complicated electricity tariffs and inadaptability of practices represent barriers to energy efficient actions. In response, this paper makes suggestions for the design of energy efficiency initiatives, policy and farm-specific eco-feedback, including: (1) Increased support around tariff navigation, (2) consideration of farmers' financial circumstances in audit recommendations, (3) a re-ordering of program instruments and (4) designing eco-feedback specifically for farmers, including hardware that supports multiple meters, and real-time water use feedback.

1. Introduction

Agriculture is the fourth most energy-intensive industry in Australia, being one of the few industries in which energy productivity has declined- by more than 21% between 2008 and 2018 [1]. Efforts to improve the sustainability and efficiency of agriculture tend to focus on land management practices and livestock emissions [2–6], with relatively less focus on electricity consumption [7]. Retail electricity prices for small and medium enterprises (SME's) have increased by over 40% since 2005 [8]. Like the majority of urban consumers, farmers lack real time information on their electricity consumption and receive monthly or quarterly feedback [9], limiting their ability to quantify the impact of energy efficient modifications or behaviour changes. Furthermore, generous feed-in tariffs for solar photovoltaic (solar PV) [10] and energy literacy initiatives (e.g. free or subsidised energy use monitors) in Australia [11] have previously been limited to single phase connections or residential dwellings only. This has left farmers with fewer incentives for implementing energy efficiency improvements such as solar PV or battery storage, or means of quantifying the effect of these measures.

This paper aims to understand the farm-level barriers and opportunities to greater energy efficiency in the Australian agricultural sector, drawing on 12 farmers' first-hand experiences with a series of on-farm energy efficiency interventions consisting of an energy audit, financial incentive to implement audit recommendations and the deployment of on-farm energy monitoring (eco-feedback) (see [12]). We take a bottom-up, farmer-centric, mixed methods approach [13], informed by social practice theory (SPT) [14–17], using interviews and self-reporting to supplement quantitative energy use data from farmers' eco-feedback devices. The paper reports on factors affecting farmers' engagement and ability to draw benefit from the interventions, building upon the wealth of literature from eco-feedback deployments in urban households [18–20]. From our findings we provide suggestions for the design of policy and agricultural energy efficiency programs. The paper is arranged as follows: (1) Energy use data before and after the audit is compared, to assess the potential of quantifying its effect, controlling for seasonality. (2) Descriptions of farmers practices and experiences are used to chart engagement with the eco-feedback dashboard over time and understand the effect on learning and behaviour change. (3) Self-reported barriers to adoption of energy efficient actions are then categorised according to: (a) *Motivation*, (b) *Ability* and (c) *Opportunity* – which are understood as central antecedents of consumer behaviour [21]. (4) After reflecting on our farmers' experiences of the eco-

* Corresponding author at: Centre for Energy Data Innovation, University of Queensland, Building 1015, 80 Meiers Rd, Long Pocket, Brisbane 4068, Australia.
E-mail address: s.snow@uq.edu.au (S. Snow).

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feedback, relative to those of residential customers as reported in literature, we provide suggestions for policy and program design.

2. Literature review

2.1. Drivers of sustainable technology adoption on farms

Literature on farmers' adoption of sustainable technology, including precision agriculture [22], agricultural robots [3], integrated pest management [6] and nutrient abatement [4] finds a range of factors affecting adoption. Propensity to adopt differs considerably based on economic factors, farm size, education, age, farm tenure and operation-specific factors [2,23]. A survey of 2439 farmers in Europe found size and access to capital represented central drivers for uptake of nutrient abatement technology, where environmental motives were present, but secondary to economic concerns [4]. Adoption of energy efficiency solutions specifically (including solar PV adoption) is affected by cost-related factors such as income, ability to obtain profits [24], financial incentives and support instruments [25], as well as cognitive factors, education attainment and age [26,27].

The adoption of any technology by farmers is also fundamentally affected by their perceptions regarding the ease of use of the technology, whether the technology may interfere with traditional knowledge/land management practices and how observable the outcomes of an adoption will be [2]. Yet these more discursive tenets of adoption are difficult to capture using largescale stated preference surveys [4]. Rationalistic theoretical framings [5,6,28] outnumber studies of non-cost factors, personal accounts and lived experience [29]. Despite being central to residential sustainability campaigns [3,6,19,22,30,31], electricity use specifically has featured less as a focus for agricultural sustainability. Instead, the primary focus has been on land management practices, e.g. fertiliser application, precision agriculture and automation [3,22]. These circumstances drive our choice to utilise a more bottom-up, farmer-centric approach to understand farmers' attitudes, practices and lived experiences of the energy audit and eco-feedback programs and determine barriers to energy efficiency.

2.2. Social practice theory

Social Practice Theory (SPT) contends that resources such as electricity are consumed as part of accomplishing everyday life. Householders are viewed as *"participants in practices, rather than consumers of aggregate resources"* [32]-*pp.2137*. The understanding and analysis of consumption as a social phenomenon overcomes the limitations of rational action theories [33,36] which understand behaviour to be individualistic, rational and based upon consciously planned decisions or cost-benefit analyses (e.g. [34]).

The suitability of SPT to energy consumption research is witnessed by a rapidly growing body of work in this area (see Corsini et al. [33] for a meta-review). SPT scholars find residential consumers' energy use practices are normative, driven by comfort, cleanliness, convenience [35,36] and practices that are interlocked with co-inhabitants [13]. Electricity demand is driven in part by evolving social norms around comfort and cleanliness, for example, higher expectations of personal and home cleanliness compared to previous generations and a growing trend towards running air conditioning or heating in unoccupied homes due to consideration of the comfort of one's pets [17]. Supporting pro-environmental behaviour therefore should not involve persuading users to make different decisions [16], but instead support awareness of the factors affecting one's consumption [37] and communicate how practices can be accomplished in less energy-intensive ways [14,16]. Despite exceptions [38], few applications of practice-based research involve farmers; none of which we could find that specifically focus on electricity consumption. In this study we were interested to understand the connection between agricultural practices and energy use, including farmers' opinions on the adaptability/elasticity of these practices.

2.3. Engagement with energy use feedback

Eco-feedback is a cornerstone of campaigns to assist householders in saving energy. It has been studied extensively, relating to its effect on behaviour and capacity to realise energy savings in households [18–20,39–44], the design of eco-feedback [45–47] and how engagement with eco-feedback fluctuates over time [19,42,43]. Findings suggest eco-feedback can facilitate a better understanding of energy usage patterns [48], improve energy literacy [49] (i.e. understanding of the role of energy in the world [50]) and produce energy savings of up to 10% [51]. Yet initial energy savings made are not always durable over time, with longitudinal studies finding mixed evidence for the persistence of behaviour changes in response to eco-feedback [19,42]. Rational energy saving opportunities identified by eco-feedback can conflict with family dynamics, limiting their effectiveness [36]. Yet Schwartz et al. [48] highlight a range of beneficial outcomes of eco-feedback deployments in the absence of quantitative behaviour change and argue that the typical framing of eco-feedback as a tool for persuasion is limiting [48]. Chalal et al. provides extensive design suggestions gathered through a community co-design process for how to increase the accessibility and intelligibility of eco-feedback to users, without a specific focus on energy saving [45].

Despite an abundance of qualitative and ethnographically informed literature on urban consumers' barriers to energy efficiency [52–54] and experiences with eco-feedback [18–20,46,55], farmer-centric research into these topics is far less abundant. In this paper we focus on farmers' experiences with energy audits and eco-feedback to better understand these factors as potential drivers of on-farm energy efficiency.

3. Methodology

Our methodology involves a mixed methods study combining quantitative data analysis with qualitative interviews and questionnaires with 12 farmers in the state of Queensland, Australia. Our study is informed by SPT insofar as our interest in how agricultural practices translate into energy use. Yet farmers' geographic separation and COVID-19 restrictions prevented us from employing more situated, ethnographic observation of practices e.g. [17,56,57]. Our methodology is closely aligned with Eon's study of energy in the home [13], using farmers' qualitative accounts to explain observations made from analysis of quantitative data.

The data gathered for this study includes:

1. Review of documentation (e.g. appraisal of audit reports, electricity bills, electricity tariffs, farm production, farm size, date of audits, audit recommendations, capital cost of investments and payback period).
2. Quantitative energy use data downloaded from the eco-feedback server.
3. Qualitative data from interviews and emailed responses to interview questions.

Details of the data gathering, and analysis are provided in more detail below.

3.1. Study context

This paper focuses on farmers involved with the "*Extended Energy Saving Program for Agriculture Business*" initiative (hereafter *"Energy Savers"*), funded by the Queensland Government and delivered by Ergon Energy in partnership with Queensland Farmers Federation (QFF) [58]. Energy Savers provided free energy audits to farmers to identify cost savings through energy efficiency measures [58] and a financial co-contribution up to AUD$20,000 towards implementing audit recommendations. In parallel to this initiative, QFF implemented a real-time energy monitoring program available to up to 50 audit participants, consisting of a *Wattwatchers* eco-feedback device [59] installed free-of-charge. This pairing of interventions reflects findings that energy audits when combined with eco-feedback have been associated with positive energy efficiency outcomes for workplace [16,31] and residential deployments [11].

Audit: The audit methodology was based on Australian/New Zealand Standard: 3598:2014 (Energy Audits) for commercial and industrial operations and included an appraisal of the use of all electrical equipment contributing to the farm's operation [60]. The energy audits were free of charge to farmers who applied to the program and were conducted between January 2019 to January 2020 [58]. Each audit involved a farm visit by a QFF representative, with data gathered on energy costs through receipts and energy bills covering the 12 months prior to the audit. Audit reports were delivered to farmers via email between May 2019 and September 2020, on average five months after the audit. This variance in the delivery of audit reports is due to (1) the audits being conducted over a 12-month period, (2) variability in preparation time of the audit reports, depending on the size and complexity of farm operations, (3) variance in the individuals undertaking the audits.

Eco-feedback: Fifty Wattwatchers eco-feedback monitors were offered free of charge to audit participants. The monitors were allocated to the first 50 audit recipients to respond to the offer. This self-selection bias toward (potentially) motivated users is a limitation common to residential deployments of energy monitoring [49]. The Wattwatchers real-time monitoring devices were installed between June 2019 and February 2020, which equates to one to nine months after farmers received their energy audit report. This variance was due to the variability in audit timing and receipt of report (mentioned above).

The Wattwatchers device measures up to six electrical circuits in a meter box. It records electricity consumption continuously, logging five-minute averages to a digital cloud [61]. Notably, 11 of the 12 participants had more than one electricity meter, e.g. secondary meter(s) in remote paddocks to supply power to irrigation pumps, separate to the general supply meter. While QFF encouraged farmers to connect the monitoring to their main supply meter, two farmers chose to connect the monitoring to a secondary (irrigation) meter (P7, P12). We discuss the implications of this later. All farmers were provided with their data on a dashboard (FluxPower [62]) accessible through a web login and viewable on computers or mobile/tablet devices. The dashboard features live electricity consumption information, various available historic comparison options and the associated cost (Fig. 1).

Despite the variance in the timing of receiving energy audit reports and eco-feedback installations, all farmers had at least one month to reflect on their audit reports prior to the eco-feedback install.

Fig. 1. Flux Power Dashboard [62].

3.2. Sampling

All 50 farmers who received the Wattwatchers energy monitors were contacted by email with an invitation to take part in interviews for this research. Twelve farmers agreed to take part, representing various agricultural operations across Queensland.

3.3. Participants

Participants were aged 22–63 years old (median 45 years old) and represented a range of agricultural operations including broadacre dryland and irrigated cropping, cattle, horticulture and viticulture and were geographically dispersed throughout Queensland, from the northern tropics (P5) to far western Queensland (P6) and the south-east (P1, P2, P7). Our participants incorporate the diversity of farming operations and climatic zones across Queensland. Yet despite the geographic separation, all farmers were customers of the one monopoly electricity retailer and shared the same jurisdictional area for energy regulation, financial incentives, and state laws.

The study was approved by the University of Queensland Office of Research (ethical approval number 2020000538). Informed written consent was obtained prior to interviews through email. Unlike other SPT research utilising more direct observations of practice [17,57], interviews were designed to be conducted by phone rather than face to face owing to the geographic separation of the participants and COVID-19 social distancing restrictions.

Interviews ranged in length from 30 to 60 min and were audio recorded. Eight of the 12 participants requested to answer the interview questions by email due to a reluctance to be interviewed and/or limited time or reliable phone signal during the day when away from the home or office. The questions emailed to farmers were copied directly from the interview question protocol (refer supplementary material), including prompts for more open-ended questions. Participants who submitted email responses were asked to provide as much detail as possible and those who provided single word or single-line responses to questions were re-contacted and asked to elaborate. This measure ensured the richness of emailed responses was comparable to those obtained in interviews. All interviews and questionnaires took place between May and June 2020 and engaged only farm owners and/or managers.

Questions were designed to obtain farmers' feedback to better understand (1) the effect of the audit and eco-feedback on their energy use and perception of energy efficiency, (2) farmers appraisals of the key drivers of changes in their energy use over the period, (3) barriers and opportunities to implementing energy efficient practices, and (4) their interest in energy sharing between farms, e.g. microgrid participation (not a focus of this study). The aim was to go beyond simply cataloguing barriers to adoption of energy efficient technology and understand aspects of farmers' lived experiences of the energy audit and eco-feedback deployment.

Queensland Farmers Federation (QFF) were additionally contacted for clarification and reflections on the issues that occurred during the meter installation process, the required adaptations to the monitoring system and other matters.

3.4. Analysis

Document review: The research team was provided with documentation from the energy audits, which included farmers' previous electricity bills, electricity tariffs, farm production information, farm size, date of audits, auditors notes, summaries of findings from audit reports, audit recommendations and associated energy/cost/emission savings, capital cost of investments and payback period. Data was categorised and tabulised (e.g. Tables 1–3).

Quantitative data: Raw hourly energy use data (in kWh) was extracted from the eco-feedback dashboard by the researchers to enable a seasonal comparison with data from the electricity bills supplied for

Table 1
Characteristics of participants.

ID	Productive activity	Age	Location (Region)	Farm area (ha)	Annual pre-audit electricity consumption from the grid (kWh)	Leading contributor to consumption	Monthly solar generation (kWh)
P1	Horticulture	22	Toowoomba	22	616,000	Refrigeration system	5000, PV
P2	Wine	63	Stanthorpe	59	100,640	Refrigeration system	3500, PV
P3	Nursery	56	Moreton Bay	425	20,000	Irrigation system	None
P4	Cotton	44	Moura	210	99,807	Irrigation system	None
P5	Sugar Cane	51	Mareeba	250	113,800	Irrigation system	2000, Pump
P6	Sheep	40	Longreach	415	65,468	Refrigeration system	1500, PV 20kw Battery
P7	Cotton	61	Toowoomba	1,860	146,114	Irrigation system	1000, PV
P8	Beef Cattle	43	Mareeba	60	10,291	Irrigation system and water heating	None
P9	Horticulture	57	Ipswich	91	144,000	Refrigeration system	500, PV
P10	Nursery	39	Sunshine Coast	212	172,117	Steam heating system	None
P11	Nursery	46	Mareeba	33	58,221	Irrigation system and water heating	100, PV
P12	Hay	39	South Burnett	61	28,191	Irrigation system	None

the audit. Monitored data was compared with energy bill data from the same time period in the previous year (refer to Table 3). The purpose of this comparison was to assess the potential influence of eco-feedback on users' energy behaviour (as done in studies of urban households [63]) with the assistance of self-reported data to contextualise the energy use data. Farmers had access to the data from their eco-feedback dashboards continuously following the installation.

Qualitative data: Interviews were transcribed verbatim with responses collated and organised as per the returned questionnaires for analysis of text. Information on demographics, energy use determinants, frequency of logins etc. were collated and tabulated. Informed by Cresswell [64], our analysis of qualitative data included the following steps:

1. Deidentify responses to protect identities.
2. Read and re-read interview/questionnaire transcripts to identify barriers to energy efficiency actions and other emergent themes.
3. Once a list of themes and barriers was compiled and checked against the original data for representation, barriers to energy efficiency were categorised into *Motivation*, *Ability* and *Opportunity* (MOA), according to the definitions in Section 3.5 below.

3.5. Framework of analysis

The aim of our qualitative analysis was to gather the broadest possible overview of farmers' values and practices concerning energy use (informing our choice of SPT methods), but equally, to employ an established structure to categorise the barriers/opportunities to energy efficiency elicited in the interviews (informing our choice of applying the MOA framework).

Motivation, Ability and *Opportunity* are understood as antecedents of consumer behaviour [21], including energy efficient purchases and behaviour changes [65]. In relation to energy consumers' behaviour [65], *Motivation* refers to personal, social and financial motivations. *Ability* refers to: *"literacy, numeracy, problem solving and research skills"* [65], and *Opportunity* relates to access to finances, tenure and structural factors, e.g. high-rise apartment dwellers lack the opportunity to install solar panels [65]. In this study, we use MOA to categorise barriers to energy efficient practices to better understand the nature of these barriers and target designs to overcome them.

4. Results and analysis

4.1. Factors and practices affecting consumption

Pre-audit electricity consumption varied widely between farms (Table 1). Linear regression of total energy consumption against farm area showed no correlation (r −0.06). Consumption was quantified in the audit and explained by participants in terms of the services provided, e.g. irrigation (P3, P4, P5, P7, P8, P10, P11), refrigeration (P1, P2, P6, P9), or the heating required to enable the growth of certain plants in nurseries (P10, P11). Irrigation practices varied according to region and individual operation. On farms where irrigation was a lead contributor to energy use (P3, P4, P5, P7, P8, P10, P11), consumption varied both seasonally and due to event-based factors such as rainfall. P5 and P10 were located in the tropics (high summer rainfall) and irrigated during the dry season only, whereas P3, P4, P7 and P12 irrigated according to seasonal crop requirements and on specific events, e.g. rainfall or when sources of surface water became available.

Farmers' detailed knowledge of their operations was in contrast to a limited understanding of their energy use. Electricity was often discussed as an operational cost, rather than a resource over which they had control. In the case of irrigation-dominant operations, farmers were highly literate of their irrigation requirements, yet the practice of irrigation was almost entirely non-discretionary. *"Our most critical* [*resource*] *is water usage, which ties with the requirement of electricity as all water reticulation is by power"* (P8). *"[Apart from energy] water is our other main issue"* (P10).

Seven of the 12 participants had installed solar PV to assist with electricity costs, but only one system (P10) was installed in response to the energy audit. Four of the seven installations were single-phase grid-connect residential scale systems. Others had a small standalone array connected directly to a water pump (P5), while P1 and P2 had invested in larger systems which supplied approximately 10% and 40% of their respective farms' electricity needs.

4.2. Audit and improvements

The main driver for participation in both the audit and energy monitoring program was the desire to identify potential operational cost savings through increased energy efficiency: "*I decided to participate in the trial to make sure we are being energy efficient and hopefully save money*" (P7). "*… find efficiencies in my energy consumption"* (P5). *"We are in the program to be accountable for our energy costs"* (P6). Environmental motivation featured only in only one farmers' decision to participate and was secondary to economic considerations: "*We have massive electricity bills each month and as well as cost savings we wanted to try to reduce our carbon footprint*" (P10). Table 2 details the audit recommendations for each farm, including which of these had been implemented at the time of the interviews.

Solar PV installation and a review of electricity tariffs were the most common recommendations from the audit. The latter is due to the electricity retailer (to whom all participants were customers) retiring and replacing many of the farm and small business tariffs with a new suite of more demand-based tariffs [66], necessitating almost all farmers switch their electricity tariff prior to July 2021.

Table 2
Audit recommendations showing those implemented ☑ and those intended to be implemented in the next 12 months (from the date of interview-May-June 2020) **[int.]**

ID	Audit report dates	Audit recommendations	Estimated cost of implementing all recommendations ($)	Improvements implemented or intended *without* audit influence
P1	November 2019	Tariff review **[int.]** Lighting system upgrade Insulation upgrade Refrigeration upgrade Upgrade solar PV to 100 kW	$420,000	Insulation and refrigeration upgrades. Completed January 2020
P2	February 2020	Tariff review **[int.]** Cold room upgrades Lighting system upgrade	$65,000	
P3	February 2020	Tariff review **[int.]** Lighting system upgrade Pump upgrades Pump replacement Heating system upgrade Install 27 kW solar PV **[int.]**	$80,000	
P4	August 2019	Tariff review Pump replacement ☑ Install 40 kW Solar PV	$100,000	
P5	December 2019	Tariff review Pump replacement **[int.]** Pump upgrades ☑ Install additional 5 kW solar PV	$40,000	
P6	November 2019	Tariff review Hot water upgrade Lighting system upgrade Refrigeration upgrade **[int.]** Upgrade solar & battery capacity Pump valve timers installed ☑	$40,000	Further timers fitted to pumps **[int.]**
P7	December 2019	Tariff review Pump replacement **[int.]** Install additional solar PV for pump	$30,000	
P8	July 2019	Tariff review Hot water upgrade ☑ Lighting system upgrade Pump replacement Install 5 and 3 kW solar PV **[int.]**	$20,000	
P9	February 2020	Tariff review Lighting system upgrade Replace evaporator fans **[int.]** Refrigeration replacement **[int.]**	$220,000	Battery storage purchase in 2021 **[int.]**
P10	July 2019	Minimise peak demand Off-peak irrigation Install 30 kW solar PV ☑	$50,000	
P11	July 2019	Tariff review Pump replacement Install additional 10 kW solar PV **[int.]** Hot water upgrade Lighting system upgrade	$40,000	
P12	August 2019	Tariff review Irrigation upgrades Install solar PV **[int.]**	$10,000	

Despite the available co-contribution of AUD$20,000 toward implementing audit recommendations [12], at the time of the interviews (May-June 2020), only five (P3, P5, P6, P8, P10) of the 12 farmers had acted upon one of their audit recommendations. All other participants reported an intention to carry through with one or more recommendation (Table 2). Three participants had made recent energy efficient retrofits prior to, or unrelated to, the audit. P1′s investment in improved refrigeration following the audit was explained as a strategic business decision that had been made prior to the audit. P9 planned to purchase battery storage to enable the utilisation of solar energy after dark, noting this intention was formed prior to the audit.

4.3. *Effect of audit recommendations on electricity use*

In attempting to quantify the effect of the audit on electricity use, we compared data from electricity bills gathered during the audit with the real-time monitoring data. This method afforded year-on-year comparison of electricity use and provided a partial control for seasonality by comparing the same season. The meter to which the real-time monitoring device was connected was compared to the corresponding meter

Table 3
Changes in Electricity Consumption on the monitored meter.

ID	Period of energy bills assessed in audit	Main loads on the monitored meter	Period of data extracted from real-time monitoring	Average monthly energy use-real-time monitoring (kWh)	Average monthly energy use-electricity bills-corresponding meter (kWh)	Change in consumption-audit year vs same period previous year (%)	Self-reported triggers
P1	Nov 2018 to Mar 2019	1. Chiller 2. Quality control room (new)	Nov 2019 to Mar 2020	14,075	5000	↑ 182%	New quality control facility
P2	Dec 2018 to April 2019	1. Coolers 2. Solar PV	Dec 2019 to April 2020	2322	1059	↑ 119%	Less solar generation
P3	Nov 2018 to April 2019	1. Pumps 2. Heating system	Nov 2019 to April 2020	830	1830	↓ 55%	None given
P4	Nov 2018 to Mar 2019	1. Pumps 2. Main supply	Nov 2019 to Mar 2020	6701	3352	↑ 200%	More production
P5	Dec 2018 to Jan 2019	1. Pumps (3)	Dec 2019 to Jan 2020	5800	5200	↑ 12%	None given
P6	Nov 2018 to Mar 2019	1. Main supply (solar and pumps) 2. Hot water and cooling systems	Nov 2019 to Mar 2020	1600	2600	↓ 38%	Better use of pumps with timers and monitoring
P8	Nov 2018 to Mar 2019	1. Hot water system 2. Pump	Nov 2019 to Mar 2020	6440	750	↑ 759%	Commissioning of industrial-scale hot water system (upgraded from gas). January 2020 (audit)
P9	Nov 2018 to Mar 2019	1. Cool rooms (4) 2. Dam Pump	Nov 2019 to Mar 2020	8200	11,800	↓ 38%	Less use of cooling room
P10	Sept 2018 to Mar 2019	1. Steam heating 2. Pumps (6)	Sept 2019 to Mar2020	16,800	16,900	< 5%	Not Applicable
P11	Nov 2018 to Mar 2019	1. Pump 2. Hot water system	Nov 2019 to Mar 2020	640	630	< 5%	Not Applicable
P12*	Feb to April 2019	1. Irrigation pump	Feb to April 2020	223	210	↑ 6%	None given

Table notes: [*] monitoring connected to irrigation pump meter(s) only.

I.D. on the previous year's electricity bills. Table 3 does not correspond to total farm energy use for P7 and P12, who connected their real-time device to a secondary irrigation meter. Farms with changes in electricity use greater than ±25% were re-contacted to attempt to understand possible triggers behind these changes, as indicated in Table 3. Data quality issues caused the exclusion of P7 from Table 3.

Table 3 demonstrates the variety of reasons behind fluctuations in energy use and the difficulty in quantifying the effect of the audit on energy use, even with self-reporting. These findings do not suggest the audit was ineffective, but rather highlights the difficulty in isolating the effect of energy efficiency measures from aggregate changes in energy use, given the large number of contributing factors.

Several participants used considerably more electricity after the energy audit compared the same period the previous year (Table 3). Yet the self-reporting demonstrates that in many cases, the changes were caused by factors unrelated to the energy audit. These include: commissioning a new quality control facility (P1), increased production (P4) and replacing gas hot water services with electric systems (P8)- the latter which markedly increased electricity consumption, but was expected to reduce overall fuel costs. P3 used 55% less but had not implemented any audit recommendations (Table 2) and could not describe why this change might have occurred. Only for P6 is an effect of the audit likely, where P6 reported fitting pump timers following the audit and realised a 38% reduction in energy use relative to the same period the previous year (Table 2). The choice of meter to which the real-time monitoring was installed also affected the quality of monitoring data. P7 and P12 went against QFF's advice and chose to connect their eco-feedback device to a secondary (e.g. irrigation) meter and for these participants the monitoring feedback does not provide a complete overview of either farm's electricity usage.

4.4. *Experiences with eco-feedback*

At the time of the interviews, participants had owned their eco-feedback device for a period of two to seven months depending on the installation date of their monitoring systems. Because of the variability in length of time since deployment and the seasonality of many farm's energy consumption, it is not reasonable to attempt to quantify the effect of the eco-feedback on energy use, and instead, we focus on self-reported engagement and behaviour changes.

(a) Engagement

Farmers volunteered to have the eco-feedback systems installed, indicative of an existing motivation to receive real-time monitoring. Yet the frequency of interactions with the eco-feedback was overall low. When asked to report on their engagement with the eco-feedback in the four months following the installation of the systems, most farmers reported accessing the dashboard only 1–2 times per month, with engagement typically declining over time (Fig. 2).

Five farmers had not yet accessed their dashboard at the time of the interview (Fig. 2). P5 reported having trouble accessing the dashboard, while P8 reported having no time to look. P7 and P12 had connected their monitoring to external irrigation meters, and hence had no data on their dashboard until pumping operations started. P4′s pumps were on the general supply meter, meaning they had access to data from other circuits, yet they did not prioritise accessing the dashboard until pumping commenced, underscoring the importance for these farmers of understanding the energy used in irrigation.

(b) Learning

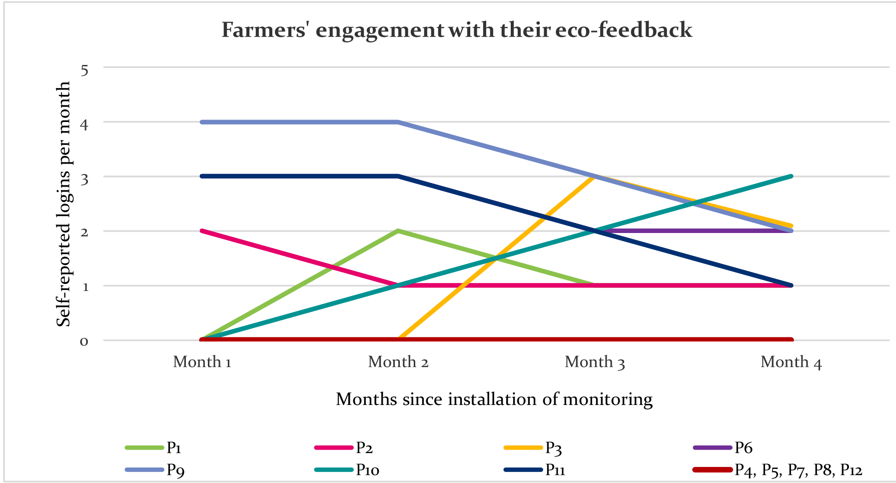

Fig. 2. Engagement with eco-feedback.

Seven of the 12 participants had engaged with their eco-feedback by the time of the interview, of which four (P1, P6, P10, P11) reported learning directly from the monitored data. This included learning about consumption peaks and daily consumption trends as a function of total electricity costs, learning to identify electrical loads, changing the time of use of certain loads, assessing the impact of solar generation on grid import, and identifying potential energy savings, e.g. upgrading air conditioning to newer models (P6).

> *"It has helped us to understand our trends in consumption with better information than provided in the bills, showing our peak demand during the day and how to achieve cost reductions"* (P1). *"Our electricity bills are based on peak consumption. If we can flatten the peaks, then we pay less for electricity. The monitoring is helping us identify when we use the most electricity and what is causing the peaks"* (P10).

P6 reported learning about the energy loads, their main energy consumption activities and the importance of energy conservation: "*we can see how much energy we use and where we can make some changes to be more beneficial to our business costs. We have seen that solar is a great way to conserve on energy. We have also learnt where our main energy uses come from" (P6)*.

(c) Behaviour changes

Despite the positive learning outcomes from the eco-feedback detailed above, there was limited evidence of either (a) learnings translating into behaviour change, or (b) the monitoring being used to quantify the effect of audit recommendations. P6 reported using the eco-feedback to measure the effect of the pump timers they had installed as per audit recommendations, yet no participant described self-identifying further behaviour change possibilities from the eco-feedback. The learning and behaviour change potential of the eco-feedback appeared to be reduced through lack of engagement and lack of adaptability of practices, which we discuss in Section 4.5.

(d) Improvements

When questioned whether the participants could think of any improvements to the eco-feedback system, or additional resources to monitor, six participants mentioned the addition of water monitoring would be useful. Water was identified throughout the interviews as a *"big issue"* (P7), *"our main issue"* (P10) and both P8 and P10 already read their own water meters regularly: *"We already monitor water use into tanks daily through water meters on all our water sources …[and]… out of the tanks as it is being used for irrigation"* (P10).

4.5. Barriers to uptake of energy efficiency improvements

Neither the audit or the eco-feedback deployment resulted in substantial changes to behaviour or prompted investment in energy efficiency. We categorise the barriers to energy efficient actions (as identified by the participants) according to *Motivation*, *Ability* and *Opportunity* [65].

4.5.1. Motivation

Upfront cost: Upfront capital cost and lengthy payback periods served to demotivate energy efficient actions in nine cases. Reflecting on the audit recommendation of installing solar PV, P4 said: *"I like the idea of solar, but it is very expensive, and I don't have land availability…I don't need it, I don't pump every day, it's not worth it for me"* (P4). Similarly, P8 mentioned: "*Irrigation is run at night-time due to wind timings and the current return of power to grid from solar does not justify the establishment costs of solar"* (P8).

Lack of evidence/feedback: The lack of ability to measure the effect of actions taken demotivated engagement from P7, P8 and P12. In these cases, the eco-feedback installation was too recent to provide data on periods of interest. P7 noted: "*We've have had a 20 kW system on our workshop shed and house for 3 years. We don't feel it has given us a satisfactory payback for the capital invested and would be reluctant to implement it elsewhere"* (P7). Achieving an accurate comparison of before/after performance could take a season or longer; P8 and P12 had not had the water availability to determine the efficiency of their pumps: "[*the eco-feedback*] *hasn't been useful yet, we have not had water*" (P12). P5 had replaced two irrigation motors in March (2020), but at the time of the interview in June, remarked: *"So far I have installed variable speed drives on two irrigation motors and the period has been too short to make an accurate comparison"* (P5).

4.5.2. Ability

Energy literacy: All farmers displayed a detailed understanding of the running costs of their businesses; however, energy use was not considered a cost over which they had any control. Two participants held a limited understanding of opportunities to improve energy efficiency beyond suggestions given in the audit and could not always correlate their eco-feedback data to on-farm practices: *"I don't know [what causes the fluctuations], could be some kind of random variation"* (P3). Aspects of *Ability* here relate closely to *Motivation*, where farmers' self-reported inability to engage with the eco-feedback due to time constraints, could also be construed as symptomatic of a lack of prioritisation of time to become energy literate, e.g.: *"we have been in critical times with the production process, we are looking at it [the eco-feedback], but we have limited time"* (P1). "*The monitoring is helping us identify when we use the most electricity and what is causing the peaks. But available time to look and analyse the data has been a limitation"* (P10).

Complicated tariffs: The energy utility to which all participants were subscribed was undergoing a review of electricity tariffs during the audit/eco-feedback period. Several farmers were subscribed to tariffs which were to become obsolete the following year and were faced with a choice of up to 11 possible tariffs, including time-of-use tariffs, demand-based tariffs and general supply tariffs [67]. Many farmers were already on more than one tariff and the complexity of the tariff systems represented a barrier to energy literacy and a cause of concern for five farmers: *"…we have not evidenced any difference between peak and non-peak consumption, prices are the same… no discount for using energy at night, you get charged the same rate"* (P3). P4 and P7 expressed concern and uncertainty over their options and decisions when their present tariffs were to expire in July 2021: *"The tariff I have allow[s] me to pump cheapest, but I don't know what to do when they eliminate it"* (P4). P7 remarked: "*…we used to be able to get cheap night-time energy and we would use that to keep cost down but that has been taken away from us…*" (P7). These quotes show that beyond the energy literacy necessary to understand tariffs (*Ability*), that *Opportunity* is also a factor, where farmers are disadvantaged by energy sector processes (e.g. tariff setting) that they cannot control.

4.5.3. Opportunity

Available funds: Up-front cost acted as a (de)motivator for energy efficiency improvements (highlighted above), yet for six farmers, cost was a structural barrier, where they simply did not have the money to implement energy efficiency improvements, irrespective of their motivation, or of the available co-contribution for implementing audit recommendations. P5 said: *"The audit recommended a solar array on one pump system. I haven't implemented it yet, costs are prohibitive"* (P5). P9 was reliant upon the co-contribution to be able to afford the audit-recommended cold room upgrade, but was dealing with issues pertaining to eligibility in the program: "*Frustratingly, we have waited for the (government) grant process, otherwise we probably would have had the cold room upgraded last year"* (P9).

Adaptability of practices: Four farmers reported a lack of adaptability of practices limiting their opportunities to become energy efficient. This was the case for irrigation-dominant operations, whose pump use related to climatic factors, which they could not control, summarised by P7: *"…we can't change when/how we pump, it is when the crop needs it and as quickly as possible!"* (P7).

5. Discussion

The relatively novel application of the energy audit with eco-feedback combination on farms complements the wealth of literature on energy efficiency initiatives aimed at urban households [20,44,46,51,68,69]. Research finds households are capable of shifting consumption to maximise utilisation of solar [70] and trading higher levels of comfort for cost savings [19]. In comparison, our farmers reported a relative lack of adaptability in their practices, where energy use was tied closely to agricultural production and dictated by factors which they could not always control, e.g. water availability, rainfall and always-on services, such as cold storage. Our findings reflect literature on farmers' adoption of sustainable technology, in that cost and economic factors represent central determinants, with environmental considerations present but secondary [4,22].

Together, the audit and eco-feedback interventions share several design features which are identified as pre-conditions for pro-environmental behaviour change in urban households, namely: (1) multiple complementary instruments, (audit, financial incentive and eco-feedback) [71], (2) participants were self-selecting, suggesting motivation to engage and participate [19], and (3) the eco-feedback dashboard visualised multiple metrics (e.g. real time consumption and various historical comparisons delivered in cost and kilowatts) which offer more utility [51,72] and deliver greater savings [73] than dashboards with fewer metrics. Yet despite a likely positive impact on energy efficiency for the five farmers who had implemented one of their audit recommendations, at the time of the interviews, the effects of the interventions were relatively modest. Only five of the total 50 audit recommendations had been implemented, farmers struggled to measure the effect of changes made from the audit and engagement with the eco-feedback was low. Barriers to implementing energy efficient actions included upfront cost, energy literacy, available time, perceived lack of evidence, complicated tariffs and inelasticity of practices. Based on our findings and related literature, in what follows, we highlight policy and program design considerations towards realising greater energy efficiency outcomes for farmers.

5.1. Policy considerations and program design

Financial instruments to support the implementation of energy efficiency solutions: Despite the 50% government co-contribution towards implementing audit recommendations (up to AUD$20,000 per farmer), our findings highlight how capital costs de-motivated action or in some cases represented prohibitive structural barriers. The audit recommendation process did not include specific consideration of each farmer's economic situation, and in some cases, the cost of improvements exceeded the farmers' means. Therefore, it is suggested to reformulate the structure of the support instruments and audit recommendations to consider farmers' economic circumstances as well as the differences in the seasonality of agricultural activities throughout the country, offering solutions with flexible deadlines for implementation, which are adapted to each client's particular reality.

Smart technology e.g. sensors and timers to automate irrigation or other machinery based on sensor readings, may represent more modestly priced mechanisms for energy saving relative to capital-intensive solar/battery installations or pump/irrigation replacement. Yet careful consideration is required here given the potential trade-offs between financial cost versus time invested, digital literacy and ease of use. Propensity to adopt on-farm technology is negatively affected by perceived difficulty of use [5] and increasing age [26,27]; the median age of Australian farmers and farm managers is 14 years older than that of the Australian workforce as a whole [74].

Specific support around tariff navigation: We suggest farmers may benefit from more detailed assistance with electricity tariffs. The tariff overhaul by the electricity retailer to whom all farmers were non-contestable customers [67], resulted in the need to switch from obsolete tariffs. The cost implications of tariff switching served as a point of anxiety and confusion for many farmers, such as those who needed to irrigate at specific times, yet faced changes to off-peak pricing structures (P4, P5, P7, P12). Irrespective of the tariff overhaul, several farms used over 100,000 kWh per year (Table 1), indicating substantial potential cost savings from judicious tariff selection. Unlike residential consumers who benefit from flat rate tariffs (rather than demand based or time-of-use tariffs), government-run websites to navigate the energy retail market (e.g. energymadeeasy.gov.au) and support for low income customers [75], equivalent services are less available for farmers. We argue further guidance, whether part of the energy audit or as a separate service or instrument, would be beneficial to farmers' energy literacy.

More generally, we advocate for a greater inclusion of farmers in the design of energy tariffs. End-users' participation in network planning is limited [17] and tariffs are typically designed according to economic, energy network and demand forecasting considerations without substantial involvement from the residents, businesses affected [76]. The tariffs available to farmers in this study cover all SME's across regional Queensland, which incorporates a great variety of operations. We argue the existing lobbying efforts to ensure farmers' representation in energy policy and price-setting, both in Australia [77] and abroad [78], is vital to protect the interests of those who lack the capital costs to insulate themselves against unattractive tariffs through solar or battery purchase, which include participants in our study.

5.2. Eco-feedback design

Despite the limited evidence of behaviour change from the eco-feedback deployment, we maintain that eco-feedback is an important constituent in energy efficiency programs. Our findings suggest those farmers who meaningfully engaged with the eco-feedback valued the ability to identify loads and measure energy use. Lack of engagement among other participants was not typically due to dissatisfaction with the system, but rather that some farmers were simply yet to draw energy from a circuit of interest to them (e.g. irrigation pumps). For these farmers it is possible the eco-feedback may become of considerable value in the future. Knowledge is a necessary pre-requisite for behaviour change [19,30,49] and research finds eco-feedback can provide value and benefits to users including energy literacy, quantification of behaviour modifications, fault detection and evidence, quite independent of any effect on energy use [48].

Order of implementation: Because of the factors above, we do not see the low engagement with the eco-feedback as a reason to remove it from future on-farm energy efficiency interventions. Rather, we suggest further research tests the effect of installing the eco-feedback *prior* to the energy audit, rather than following the audit. Our findings highlight how variability in seasons or crop cycles means farmers require longer timeframes (relative to residential consumers) to satisfactorily determine the effect of certain modifications or retrofits. Installing eco-feedback 12 months prior to the energy audit allows farmers (and auditors) to determine a baseline of their energy use. Even if some farmers do not engage with their eco-feedback (as in our study), the 12-months of data gathered still provide a greater evidence base for auditors and a tool to visually convey the effect of infrastructural or behavioural modifications to farmers. For those farmers who *do* engage in their dashboard data prior to the audit, a greater understanding of ones' electrical loads may serve to increase understanding and propensity to adopt cost-effective audit recommendations, given energy literacy is identified as pre-requisite for behaviour change [37].

Supporting multiple meters, multiple tariffs: We suggest eco-feedback for farmers should be capable of measuring multiple meters and support the calculation of multiple tariffs. Farmers in our study received a Wattwatchers real-time monitoring device, which is suitable for residential applications (i.e. each unit is capable of measuring circuits in only one meterbox). Yet 11 of the 12 participants had more than one electricity meter and hence lacked a complete overview of their energy use. We suggest engagement and satisfaction may have been higher if all farmers had all their electricity meters monitored. The increased cost of multiple energy monitoring units in farm-based energy efficiency programs should be considered against the potential improvements in engagement.

Connection to water metrics: In Australia's dry climate, water is culturally valued [79,80] and vital to agriculture [81]. Irrigation/reticulation was a leading contributor to electricity consumption for seven of the 12 participants (Table 1). Six participants suggested water as a useful further metric to display on the eco-feedback; two already read their water meters; and a further two wilfully ignored QFF's advice and attached their real-time monitoring device to a single irrigation pump meter, at the expense of understanding all other aspects of their farm's energy use. Accordingly, we suggest on-farm eco-feedback should be accompanied by, or connected to, sub-metering for water, and incorporate related measurements, e.g. soil moisture, water storage levels, irrigator settings or self-input for diesel purchase. For the irrigation-dominant farmers in our sample, these features would better align the eco-feedback information with farmers' practices, better relate irrigation energy use to water use and potentially constitute a stronger incentive for eco-feedback engagement.

5.3. Limitations and future work

SPT from a distance: SPT is a challenge for rural and geographically dispersed farmers and our study represents a non-standard implementation of SPT methods. Independent of the COVID-19 restrictions during our study, traditional ethnographic and observational methods used by SPT scholars, e.g. home 'tours' [17,56], video interviews [57] or situated interviews or observations [16,19] were not suitable, given the extreme distances between farms. Even telephone interviews were problematic for certain farmers whose limited cell phone coverage on paddocks drove a preference to respond via email. We acknowledge these as limitations of our study, but point to the value of SPT generally in understanding barriers and facilitators of technology adoption and providing a greater depth of insight relative to closed question or stated preference surveys [4]. Future SPT studies of farmers may consider methodological adaptations such as the Self-Authored Video Interview [20], Cultural Probes [82] or other methods which leverage participant generated content for insight into attitudes and practices.

Sample size and monitoring duration: This study is characterised by a limited sample size, a likely self-selection bias and relatively short monitoring timeframe for energy use data. In relation to the sample size, our experience is similar to other researchers, where farmers' reluctance to participate and time/communication constraints are reported as barriers to deeper engagement [83]. Given the long timeframes required for suitable comparisons of on-farm energy use due to crop cycles and seasonality, we suggest complementary future work could focus on more longitudinal assessments of practice and collect energy data for periods greater than 12 months. Similarly, because of these timeframe limitations, we have not made a determination on the success or failure of the program, nor provided detailed design suggestions for the eco-feedback system. We argue the relevance of eco-feedback as a constituent in on-farm energy monitoring programs needs to be established before consideration of more detailed aspects of eco-feedback design for farmers, e.g. dashboard design, information placement and usability concerns. Co-design frameworks (e.g. [45]) offer a possibility for meaningfully collaborating with farmers in eco-feedback design which we feel will be vital in this space in future work.

A "regional" focus: Our study is from a specifically Australian context. Yet the barriers identified may be of interest (although not necessarily generalisable) to scholars and farmers from other countries. A strength of our sample is the shared jurisdiction among all the participants, where despite geographic separation, all participants were non-contestable customers of the same monopoly electricity retailer and had access to the same suite of electricity tariffs and government incentives. Soil type, water availability, farm types and farming methods can vary substantially even within a local geographic region [84] and for studies of on-farm energy efficiency, we suggest that sampling from a shared jurisdictional region should be prioritised equally to geographic/climatic constraints. In future work, sampling could be further targeted by focusing on a specific type of operation (e.g. livestock, cropping, horticulture, viticulture), in contrast to our sample which incorporates a range of operation types.

6. Conclusion

Agricultural underpins Australia's food security, providing 93% of all domestic food supplies and $60 billion per year to GDP [25]. Energy efficiency including electricity conservation and eco-feedback in agriculture remains an under-explored space [85]. This paper contributes an overview of farmers' experiences from an energy audit and eco-feedback deployment. Findings point to a likely positive impact of the interventions on overall energy use across the sample, but these impacts are modest and difficult to quantify. We identify several barriers to adoption of energy efficient actions, categorised according to *Motivation, Opportunity* and *Ability*. In response to these barriers, this paper has made four suggestions related to policy, program and eco-feedback design, which include: (1) Considerations on the design of financial instruments, (2) Specific support around tariff navigation, (3) Re-ordering the provision of program instruments to deploy eco-feedback prior to audits and further incentives, and (4) Designing eco-feedback to better cater for farmers, including supporting multiple meters, tariffs and connection to water use metrics.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

[1] Australian Farm Institute, The impacts of energy costs on the Australian agriculture sector, 2018. https://www.farminstitute.org.au/wp-content/uploads/woocommerce_uploads/2020/08/energy-report_web-4rtqda.pdf. (Accessed 4/3/2021).
[2] C.P. Bishop, C.R. Shumway, P.R. Wandschneider, Agent heterogeneity in adoption of anaerobic digestion technology: integrating economic, diffusion, and behavioral innovation theories, Land Econ. 86 (3) (2010) 585–608, https://doi.org/10.3368/le.86.3.585.
[3] T. Groher, K. Heitkämper, A. Walter, F. Liebisch, C. Umstätter, Status quo of adoption of precision agriculture enabling technologies in Swiss plant production, Precis. Agric. 21 (6) (2020) 1327–1350, https://doi.org/10.1007/s11119-020-09723-5.
[4] M.T. Konrad, H.Ø. Nielsen, A.B. Pedersen, K. Elofsson, Drivers of farmers' investments in nutrient abatement technologies in Five Baltic Sea Countries, Ecol. Econ. 159 (2019) 91–100, https://doi.org/10.1016/j.ecolecon.2018.12.022.
[5] T. Rehman, K. McKemey, C.M. Yates, R.J. Cooke, C.J. Garforth, R.B. Tranter, J. R. Park, P.T. Dorward, Identifying and understanding factors influencing the uptake of new technologies on dairy farms in SW England using the theory of reasoned action, Agric. Syst. 94 (2) (2007) 281–293, https://doi.org/10.1016/j.agsy.2006.09.006.
[6] R. Rezaei, L. Safa, C.A. Damalas, M.M. Ganjkhanloo, Drivers of farmers' intention to use integrated pest management: integrating theory of planned behavior and norm activation model, J. Environ. Manage. 236 (2019) 328–339, https://doi.org/10.1016/j.jenvman.2019.01.097.
[7] R. Madushanki, M.N. Halgamuge, W.S. Wirasagoda, A. Syed, Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review, International Journal of Advanced Computer Science and Applications 10 (2019) 11-28. 10.14569/IJACSA.2019.0100402.
[8] Australian Energy Market Commission, Residential Electricity Price Trends 2020, Australian Energy Market Commission, Sydney, NSW, 2019, pp. 34-34. https://www.aemc.gov.au/market-reviews-advice/residential-electricity-price-trends-2020. (Accessed 2021-11-04).
[9] Ergon Energy, Retail energy account options, 2021. https://www.ergon.com.au/retail/business/account-options. (Accessed 13/10/2020).
[10] J. Sommerfeld, L. Buys, K. Mengersen, D. Vine, Influence of demographic variables on uptake of domestic solar photovoltaic technology, Renew. Sustain. Energy Rev. 67 (2017) 315–323, https://doi.org/10.1016/j.rser.2016.09.009.
[11] Hope Australia, More and more Queenslanders get ClimateSmart 2012. http://hopeaustralia.org.au/uploads/media/Article_Climate_Smart_Home_Service_edited.pdf. (Accessed 06/05/2020).
[12] Q. Government, Energy saving programs for agricultural businesses, 2018. https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/agribusiness/energy-efficiency/energy-saving-programs. (Accessed 03/04/2020).
[13] C. Eon, J.K. Breadsell, G.M. Morrison, J. Byrne, The home as a system of practice and its implications for energy and water metabolism, Sustainable Product. Consum. 13 (2018) 48–59, https://doi.org/10.1016/j.spc.2017.12.001.
[14] E. Shove, G. Walker, What is energy for? social practice and energy demand, Theory, Culture Soc. 31 (5) (2014), https://doi.org/10.1177/0263276414536746.
[15] E. Shove, M. Watson, N. Spurling, Conceptualizing connections: energy demand, infrastructures and social practices, Eur. J. Soc. Theory 18 (3) (2015) 274–287, https://doi.org/10.1177/1368431015579964.
[16] T. Hargreaves, Practice-ing behaviour change: applying social practice theory to pro-environmental behaviour change, J. Consumer Culture 11 (1) (2011) 79–99, https://doi.org/10.1177/1469540510390500.
[17] Y. Strengers, S. Pink, L. Nicholls, Smart energy futures and social practice imaginaries: forecasting scenarios for pet care in Australian homes, Energy Res. Social Sci. 48 (2019) 108–115, https://doi.org/10.1016/j.erss.2018.09.015.
[18] A. Grønhøj, J. Thøgersen, Feedback on household electricity consumption: learning and social influence processes, Int. J. Consumer Stud. 35 (2) (2011) 138–145, https://doi.org/10.1111/j.1470-6431.2010.00967.x.
[19] T. Hargreaves, M. Nye, J. Burgess, Keeping energy visible? exploring how householders interact with feedback from smart energy monitors in the longer term, Energy Policy 52 (2013) 126–134, https://doi.org/10.1016/j.enpol.2012.03.027.
[20] S. Snow, D. Vyas, M. Brereton, When an eco-feedback system joins the family, Pers. Ubiquit. Comput. 19 (5–6) (2015) 929–940, https://doi.org/10.1007/s00779-015-0839-y.
[21] D.J. MacInnis, B.J. Jaworski, Information processing from advertisements: toward an integrative framework, J. Market. 53 (4) (1989) 1–23, https://doi.org/10.1177/002224298905300401.
[22] V. Vecchio, G.P. Agnusdei, P. Miglietta, F. Capitanio, Adoption of precision farming tools: the case of Italian farmers, Int. J. Environ. Res. Public Health 17 (3) (2020) 869, https://doi.org/10.3390/ijerph17030869.
[23] G.D. Lynne, Modifying the neo-classical approach to technology adoption with behavioural science models, J. Agric. Appl. Econ. 27 (1) (1995) 67–83, https://doi.org/10.22004/AG.ECON.15322.
[24] J. Ge, L.-A. Sutherland, J.G. Polhill, K. Matthews, D. Miller, D. Wardell-Johnson, Exploring factors affecting on-farm renewable energy adoption in Scotland using large-scale microdata, Energy Policy 107 (2017) 548–560, https://doi.org/10.1016/j.enpol.2017.05.025.
[25] National Farmers Federation, 2030 Roadmap, 2019. https://nff.org.au/wp-content/uploads/2020/02/NFF_Roadmap_2030_FINAL.pdf. (Accessed 11/04/2020).
[26] G. Tate, A. Mbzibain, S. Ali, A comparison of the drivers influencing farmers' adoption of enterprises associated with renewable energy, Energy Policy 49 (2012) 400–409, https://doi.org/10.1016/j.enpol.2012.06.043.
[27] J.A. Bailey, R. Gordon, D. Burton, E.K. Yiridoe, Factors which influence Nova Scotia farmers in implementing energy efficiency and renewable energy measures, Energy (Oxford) 33 (9) (2008) 1369–1377, https://doi.org/10.1016/j.energy.2008.05.004.
[28] L. Guerin, T. Guerin, Constraints to the adoption of innovations in agricultural research and environmental management: a review, Aust. J. Exp. Agric. 34 (4) (1994) 549, https://doi.org/10.1071/EA9940549.
[29] M. Sarker, An introduction to agricultural anthropology: pathway to sustainable agriculture, J. Sociol. Anthropol. 1(1) (2017) 47-52. 10.12691/jsa-1-1-7.
[30] K. Buchanan, R. Russo, B. Anderson, The question of energy reduction: the problem (s) with feedback, Energy Policy 77 (2015) 89–96, https://doi.org/10.1016/j.enpol.2014.12.008.
[31] C. Meath, M. Linnenluecke, A. Griffiths, Barriers and motivators to the adoption of energy savings measures for small- and medium-sized enterprises (SMEs): the case of the ClimateSmart Business Cluster program, J. Cleaner Prod. 112 (2016) 3597–3604, https://doi.org/10.1016/j.jclepro.2015.08.085.
[32] Y. Strengers, Designing eco-feedback systems for everyday life, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2011, pp. 2135–2144, https://doi.org/10.1145/1978942.1979252.
[33] F. Corsini, R. Laurenti, F. Meinherz, F. Appio, L. Mora, The advent of practice theories in research on sustainable consumption: past, current and future directions of the field, Sustainability 11 (2) (2019) 341, https://doi.org/10.3390/su11020341.
[34] I. Ajzen, The theory of planned behavior, Organ. Behav. Hum. Decis. Process. 50 (2) (1991) 179–211, https://doi.org/10.1016/0749-5978(91)90020-T.
[35] E. Shove, Users, technologies and expectations of comfort, cleanliness and convenience, Innovation, Eur. J. Social Sci. Res. 16 (2) (2003) 193–206, https://doi.org/10.1080/13511610304521.
[36] Y. Strengers (Ed.), Smart Energy Technologies in Everyday Life, Palgrave Macmillan, London, 2013.
[37] A. Faruqui, S. Sergici, A. Sharif, The impact of informational feedback on energy consumption—a survey of the experimental evidence, Energy 35 (4) (2010) 1598–1608, https://doi.org/10.1016/j.energy.2009.07.042.
[38] F. Redhead, S. Snow, D. Vyas, O. Bawden, R. Russell, T. Perez, M. Brereton, Bringing the Farmer Perspective to Agricultural Robots, CHI '15: CHI Conference on Human Factors in Computing Systems, ACM, 2015, pp. 1067-1072. (Accessed 2021-04-16 02:18:13).
[39] Coalition for Community Energy, National Community Energy Strategy, 2015. http://c4ce.net.au/nces/wp-content/uploads/2015/04/NCES_2015_Final01.pdf. (Accessed 19/04/2020).
[40] T. Webb, Y. Benn, B. Chang, Antecedents and consequences of monitoring domestic electricity consumption, J. Environ. Psychol. 40 (2014) 228–238, https://doi.org/10.1016/j.jenvp.2014.07.001.
[41] O. Omitaomu, Profiling Real-Time Electricity Consumption Data for Process Monitoring and Control, IIE Annual Conference, Institute of Industrial and Systems Engineers (IISE), Norcross, 2013, pp. 59–66.
[42] G. Ma, J. Lin, N. Li, Longitudinal assessment of the behavior-changing effect of app-based eco-feedback in residential buildings, Energy Build. 159 (2018) 486–494, https://doi.org/10.1016/j.enbuild.2017.11.019.
[43] S. Snow, L. Buys, P. Roe, M. Brereton, Proceedings of the 25th Australian Computer-Human Interaction Conference, ACM, 2013, pp. 245–254.
[44] G. Wood, R. Day, E. Creamer, D. van Der Horst, A. Hussain, S. Liu, A. Shukla, O. Iweka, M. Gaterell, P. Petridis, N. Adams, V. Brown, Sensors, sense-making and sensitivities: UK household experiences with a feedback display on energy

consumption and indoor environmental conditions, Energy Res. Social Sci. 55 (2019) 93–105, https://doi.org/10.1016/j.erss.2019.04.013.
[45] M.L. Chalal, B. Medjdoub, R. Bull, R. Shrahily, N. Bezai, M. Cumberbatch, From discovering to delivering: a critical reflection on eco-feedback, application design, and participatory research in the United Kingdom, Energy Res. Social Sci. 68 (2020), https://doi.org/10.1016/j.erss.2020.101535.
[46] J. Froehlich, L. Findlater, J. Landay, The design of eco-feedback technology, in: Proceedings of the 28th Conference on Human Factors in Computing Systems, 2010, pp. 1999–2008.
[47] Y.A.A. Strengers, Designing eco-feedback systems for everyday life, Proceedings of the 2011 annual conference on Human factors in computing systems – CHI '11, 2011.
[48] T. Schwartz, G. Stevens, T. Jakobi, S. Denef, L. Ramirez, V. Wulf, D. Randall, What people do with consumption feedback: a long-term living lab study of a home energy management system, Interact. Comput. 27 (6) (2015) 551–576, https://doi.org/10.1093/iwc/iwu009.
[49] K. Buchanan, R. Russo, B. Anderson, Feeding back about eco-feedback: How do consumers use and respond to energy monitors? Energy Policy 73 (2014) 138.
[50] S. Hogan, A. Pascale, A. Cetois, P. Ashworth, NERA Report: Building Australia's Energy Literacy, in: S. Industry, Energy and Resources (Ed.) National Energy Resources Australia (NERA), Australia, 2018.
[51] K. Carrie Armel, A. Gupta, G. Shrimali, A. Albert, Is disaggregation the holy grail of energy efficiency? the case of electricity, Energy Policy 52 (2013) 213–234, https://doi.org/10.1016/j.enpol.2012.08.062.
[52] B.S. Reddy, Barriers and drivers to energy efficiency – a new taxonomical approach, Energy Convers. Manage. 74 (2013) 403–416, https://doi.org/10.1016/j.enconman.2013.06.040.
[53] G. Warren-Myers, C. Kain, K. Davidson, The wandering energy stars: the challenges of valuing energy efficiency in Australian housing, Energy Res. Social Sci. 67 (2020), 101505, https://doi.org/10.1016/j.erss.2020.101505.
[54] H. Fan, I.F. MacGill, A.B. Sproul, Statistical analysis of drivers of residential peak electricity demand, Energy Build. 141 (2017) 205–217, https://doi.org/10.1016/j.enbuild.2017.02.030.
[55] T. Hargreaves, M. Nye, J. Burgess, Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors, Energy Policy 38 (10) (2010) 6111–6119, https://doi.org/10.1016/j.enpol.2010.05.068.
[56] L. Nicholls, Y. Strengers, Peak demand and the 'family peak' period in Australia: understanding practice (in)flexibility in households with children, Energy Res. Social Sci. 9 (2015) 116–124, https://doi.org/10.1016/j.erss.2015.08.018.
[57] S. Pink, K.L. Mackley, Video and a sense of the invisible: approaching domestic energy consumption through the sensory home, Sociol. Res. Online 17 (1) (2012) 87–105, https://doi.org/10.5153/sro.2583.
[58] Queensland Farmers' Federation, Energy Savers, 2020. https://www.qff.org.au/projects/energy-savers/. (Accessed 23/03/2020).
[59] Queensland Farmers' Federation, Technology helping farms reduce their energy bills, 2020. https://www.qff.org.au/blog/technology-helping-farms-reduce-energy-bills/. (Accessed 18/03/2020).
[60] ERGON Energy, Choosing an energy efficiency consultant. [accessed 26 March 2021], 2019. https://www.ergon.com.au/retail/business/business-resources/choosing-an-energy-efficiency-consultant.
[61] Wattwatchers, The amazingly flexible Auditor range of Energy IoT devices, 2020. https://wattwatchers.com.au/products/hardware/. (Accessed 18/02/2020).
[62] FLUXPOWER, What is Fluxpower?, 2020. https://www.fluxpower.io/. (Accessed 13/03/2020).
[63] GDS Associates, Whole Farm Energy Management, 2018. https://mn.gov/commerce-stat/pdfs/card-report-whole-farm-energy.pdf. (Accessed 15/04/2020).
[64] J.W. Creswell, Qualitative Inquiry and Research Design: Choosing Among Five Traditions, Sage Publications, Thousand Oaks, Calif., 1998.
[65] Back to back Research, Energy Consumers Australia. Consumers Sentiment and Behaviour., ECA, Australia, 2019. https://energyconsumersaustralia.com.au/wp-content/uploads/Consumer-sentiment-and-behaviour.pdf.
[66] Ergon Energy Retail, Obsolete tariffs expiring in 2021, 2020. https://www.ergon.com.au/retail/business/tariffs-and-prices/transitional-tariffs-expiring-in-2021. (Accessed 11/03/2020).
[67] ERGON Energy Retail, Small business tariffs, 2020. https://www.ergon.com.au/retail/business/tariffs-and-prices/small-business-tariffs. (Accessed 04/04/2020).
[68] S. Darby, The effectiveness of feedback on energy consumption. A Review for DEFRA of the Literature on Metering, Billing and Direct Displays, Environmental Change Institute, University of Oxford, Oxford, 2006, pp. 26–26.
[69] C. Fischer, Feedback on household electricity consumption: a tool for saving energy? Energ. Effi. 1 (1) (2008) 79–104, https://doi.org/10.1007/s12053-008-9009-7.
[70] J. Palm, M. Eidenskog, R. Luthander, Sufficiency, change, and flexibility: Critically examining the energy consumption profiles of solar PV prosumers in Sweden, Energy Res. Social Sci. 39 (2018) 12–18, https://doi.org/10.1016/j.erss.2017.10.006.
[71] R.K. Jain, J.E. Taylor, G. Peschiera, Assessing eco-feedback interface usage and design to drive energy efficiency in buildings, Energy Build. 48 (2012) 8–17, https://doi.org/10.1016/j.enbuild.2011.12.033.
[72] R. Ford, B. Karlin, Graphical displays in eco-feedback: a cognitive approach, Design, User Experience, and Usability. Web, Mobile and Product Design, Springer Berlin Heidelberg, Berlin, Heidelberg, 2013, pp. 486–495.
[73] J.S. Brandsma, J.E. Blasch, One for all? – the impact of different types of energy feedback and goal setting on individuals' motivation to conserve electricity, Energy Policy 135 (110992) (2019), https://doi.org/10.1016/j.enpol.2019.110992.
[74] B. Binks, N. Stenekes, H. Kruger, R. Kancas, Snapshot of Australia's Agricultural Workforce, 2019. https://www.agriculture.gov.au/abares/products/insights/snapshot-of-australias-agricultural-workforce. (Accessed 11/3/2021).
[75] Australian Government, Low Income Energy Efficiency Program (LIEEP). [accessed 12 January 2021], 2016. https://www.energy.gov.au/publications/low-income-energy-efficiency-program-lieep. (Accessed 12 January 2021).
[76] M. Ansarin, Y. Ghiassi-Farrokhfal, W. Ketter, J. Collins, The economic consequences of electricity tariff design in a renewable energy era, Appl. Energy 275 (2020), https://doi.org/10.1016/j.apenergy.2020.115317.
[77] Queensland Farmers' Federation, Response to QCA Interim consultation paper: Regulated retail electricity prices for 2021-22 (January 2021), 2021. https://www.qff.org.au/wp-content/uploads/2017/04/20210205-QFF-Submission-to-QCA-QCA-regulated-retail-electricity-prices-for-2021-22-WEB.pdf. (Accessed 22/02/2021).
[78] R. Birner, N. Sharma, The politics of electricity supply to Agriculture: Analysis of political actors, discourses, and strategies, The political economy of agricultural policy reform in India, INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE (IFPRI), India, 2011, p. 27.
[79] Z. Sofoulis, Big water, everyday water: a sociotechnical perspective, Continuum 19 (4) (2005) 445–463, https://doi.org/10.1080/10304310500322685.
[80] Y. Strengers, C. Maller, Materialising energy and water resources in everyday practices: insights for securing supply systems, Global Environ. Change 22 (3) (2012) 754–763, https://doi.org/10.1016/j.gloenvcha.2012.04.004.
[81] L. Crase, B. Dollery, Water rights: a comparison of the impacts of urban and irrigation reforms in Australia, Austral. J. Agric. Resour. Econ. 50 (3) (2006) 451–462, https://doi.org/10.1111/j.1467-8489.2006.00358.x.
[82] W.W. Gaver, A. Boucher, S. Pennington, B. Walker, Cultural probes and the value of uncertainty, Interactions 11 (5) (2004) 53–56, https://doi.org/10.1145/1015530.1015555.
[83] M.T. Firrisa, I. van Duren, A. Voinov, Energy efficiency for rapeseed biodiesel production in different farming systems, Energ. Effi. 7 (1) (2014) 79–95, https://doi.org/10.1007/s12053-013-9201-2.
[84] J. Bouma, Using Soil Survey Data for Quantitative Land Evaluation, Advances in Soil Science, Springer-Verlag, New York, 1989, pp. 177–213.
[85] L.G. Smith, A.G. Williams, B.D. Pearce, The energy efficiency of organic agriculture: a review, Renewable Agric. Food Syst. 30 (3) (2015) 280–301, https://doi.org/10.1017/S1742170513000471.