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Looking beyond installation: Why households struggle to make the most of solar hot water systems

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HIGHLIGHTS

- We interview Australian households about their experience with SHW systems.
- We identify active and passive users of SHW. Active users tend to be dissatisfied with their system.
- Passive users tend to be satisfied but have relatively inefficient systems.
- Householders struggle to integrate hot water use and system operation, compromising efficiency.
- Policy should encompass pre and post-installation support as much as incentives to install.

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ABSTRACT

This paper examines household responses to sustainability issues and adoption of energy saving technologies. Our example of solar hot water systems highlights the complexity and variability of responses to low-carbon technologies. While SHW systems have the potential to provide the majority of household hot water and to lower carbon emissions, little research has been done to investigate how SHW systems are integrated into everyday life. We draw on cultural understandings of the household to identify passive and active users of SHW systems and utilize a model that illustrates how technology use is dependent on inter-relations between cultural norms, systems of provision, the material elements of homes, and practice. A key finding is that households can be ill-prepared to make the most of their SHW systems and lack post-installation support to do so. Thus, informed and efficient use of SHW systems is hit and miss. Current policy is largely aimed at subsidizing purchase and installation on the assumption that this is sufficient for emission reduction goals. Our analysis provides evidence to the contrary. Areas we highlight for policy and practice improvement are independent pre-purchase advice, installation quality, and practical guidance on system operation and interaction with patterns of hot water use.

1. Introduction

Across the global north, governments at many scales and to varying degrees have sought to align everyday household practices with energy reduction targets. Governments have supported the installation and use of products such as solar panels, home insulation, water tanks, and light globes in efforts to reduce household greenhouse gas emissions, water and energy consumption in response to climate change (de la Rue du Can et al., 2014; Head et al., 2014). In Australia, where the authors are based, the government has pursued a decade-long strategy to expand the use of low-emission water heaters, such as solar hot water (SHW) systems, as part of the National Strategy for Energy Efficiency (Council of Australian Governments, 2010). The National Strategy aims to decrease household electricity consumption by phasing out energy intensive electric hot water systems used in half of all Australian

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households (Council of Australian Governments, 2010). The policy is essentially three-pronged. First, it aims to modify attitudes and behavior through the provision of 'clear, consistent and credible information on energy efficient products and services' (Council of Australian Governments, 2010, p. 11). Second, financial incentives in the form of rebates are offered to offset the costs of installation and to assist households to install low emission hot water heaters. Third, the strategy aims to increase the uptake of energy efficient products and technologies reducing regulatory and other barriers to their purchase and installation (Council of Australian Governments, 2010). While installation rates have slowed, significant growth in total Australian SHW systems installations (from 212,423 in 2007 to 901,923 in 2014 according to the Clean Energy Council, 2015) reflects both these policy settings and consumer interest in energy efficient technology. However, as we show in this paper, there is evidence that SHW systems do not always achieve their energy saving potential.

While such policies have the potential to substantially enhance energy efficiency through the regulation of performance codes and standards for technologies and products, they work on the assumption that well-informed consumers act in rational and responsible ways and have access to appropriate information and support. Although many of these technologies, practices and behaviors are increasingly considered mainstream (energy efficient light bulbs, water saving), it is unclear why the uptake of technologies and products does not always produce the intended outcomes (Hobson, 2002, 2003; Strengers, 2011). One reason is that the effectiveness of technologies to reduce carbon emissions is usually considered in the light of calculable scientific, technical knowledge and often overlooks how their implementation and use plays out within the constraints and complexities of everyday life. Our aim in this paper is to examine how such oversights unfold in the case of household experiences of SHW systems.

Our specific focus is not so much a comprehensive study of SHW within households in the context of broader social and material networks-though we acknowledge previous cultural research that has provided rich empirically-based insights into household engagement with consumption, transport, and home energy technologies, (for example, Hitchings et al., 2013, 2015; Hobson, 2003; Hopkins and Stephenson, 2014; Klocker et al., 2012; Organo et al., 2013; Stanes et al., 2015; Waitt and Harada, 2012; Wallenborn and Wilhite, 2014). Rather, we aim to build on a key conceptual insight of such work – that policies, technologies and people are interdependent – to identify household engagements with a particular energy technology. We ask whether such interdependencies act to generate movement, or lack thereof, towards more energy efficient lifestyles (Head et al., 2013). We focus on SHW systems partly due to the prominence of the policy and incentive system described above and because theoretically, and in practice, the installation of SHW systems can provide up to 90 per cent of domestic hot water needs, and reduce power bills by 50–85 per cent (Energy Saving Trust, 2011; Harris, 2011; Solahart, 2013; Solar Edwards, 2013). However, while electricity use per household decreased by 23 per cent from 2002–03 to 2011–12, it is unclear what role SHW systems played in this shift (Australian Bureau of Statistics, 2012). There is existing evidence to suggest that their role may not be as significant as is possible. In the UK, the efficacy of solar hot water systems has been affected by tank size, installation, and consumption patterns. Some systems provide almost no energy consumption savings if not installed and managed appropriately (Energy Saving Trust, 2011). In Brazil, Giglio et al., (2014) found that only 47% of households with SHW systems showed 'good' energy savings while 37% showed 'low' or zero energy savings. In Australia, one case study highlighted installation problems that led to 'zero solar performance' or 'dramatic underperformance' (Miller and Buys, 2010). This paper explores household cultural dynamics in relation to SHW installation and use, moving towards an explanation for such disappointing outcomes.

In order to consider how policies, SHW systems and people are inter-dependent the paper is structured into four sections. The first section outlines approaches to researching household practices in relation to sustainability and provides a rationale for the cultural approach adopted. We examine household sustainability literature to better understand how relations between policy, technologies and people are always dependent on a range of cultural and social norms that manifest in particular and variable ways (Gibson et al., 2011a; Stephenson et al., 2015). We discuss zones of traction and friction (Head et al., 2013) where the physical elements of houses and systems of provision intersect with policies, people and places in ways that enable or constrain behavioral and environmental outcomes. The second section examines SHW system design and discusses how they may relate to household responses to energy efficiency programs and technologies. The third section presents results from an empirical research project in Wollongong, Australia, with twenty householders who had installed SHW systems. We discuss results in terms of passive and active SHW users, and overall energy efficiencies. Finally, section four concludes by reiterating the need for a more in-depth understanding of the way that policies, technologies, people and ideas are co-dependent, in ways that can produce contradictory outcomes.

1.1. Households, sustainability, and domestic technology

1.1.1. The household in sustainability research

Various disciplines have provided insights into household consumption and energy use and behavior. Stern (2014) highlights the contributions of economics, psychology, sociology and of approaches based in rational choice models and traditional quantitative socio-demographic methodologies more generally. Psychologists have highlighted the importance of an ecological world view for encouraging households to alter their practices in the interests of sustainability and the tendency for easy pro-environmental choices to be made while those that are more personally challenging are neglected (Steg et al., 2014). More recently, economists Asensio and Delmas (2015, p. E514), using a randomized controlled trial, found that 'nonprice incentives can effectively induce energy conservation' to a greater extent than price information.

Yet while these approaches suggest that personal beliefs and social and cultural influences can influence decisions about energy use and conservation, 'a more comprehensive understanding [of them] requires examination of the mechanisms by which they matter' (Stern, 2014, p. 43). They tend to overlook, for example, the way material elements and relationships coalesce in the household setting and are experienced through everyday practices (Stephenson et al., 2015; Waitt et al., 2012).

Within mainstream climate change policy paradigms, the household is presented as a coherent unit from which to conveniently measure and calculate the flows of energy, water and materials and a fruitful site of policy intervention (Head et al., 2013; Lane and Gorman-Murray, 2011). It is a key scale of social organization for pro-environmental behaviour (Gibson et al., 2011b; Lane and Gorman-Murray, 2011; Reid et al., 2009; Tudor et al., 2011), yet research has lagged on how the promotion of energy efficient technologies such as SHW systems work alongside social norms, everyday practices and material systems (though see Shove et al., 2012). We argue here for conceptualizing the household as a nexus of inter-dependent people, beliefs, ideas, material elements, and flows (such as of energy into a house).

In NSW, similar to elsewhere in the world, the installation of SHW systems has been encouraged through economic incentives on the assumption that increased rates of installation will reduce energy consumption (Ferrari et al., 2012). Householders are expected to act as co-operative agents within a paternalistic soft policy framework to achieve desired environmental outcomes (Jones et al., 2011). At the policy level, a range of regulatory processes has been developed in order to 'responsibilise' (Lemke, 2001) consumers into becoming carbon conscious individuals in an attempt to facilitate greater household sustainability. Yet this approach positions householders as passive 'consumers' (Slocum, 2004) and overlooks how inter-dependencies with other actors, ideas and technologies affect behaviour. In order to overcome this reductionist line of thought we draw on thinking that positions the household in relational terms.

In relational thinking, the household is not conceived of as a discrete and rigidly bounded entity constituting a particular social-geographical scale. Rather it is seen as entangled with other actors, big and small, human and non-human, at various scales (Bennett, 2010) and as embodying 'forces, processes, outcomes, and responses' (McGuirk, 1997, p. 482). Here, multiple practices and networks work to create, sustain or disrupt particular outcomes or configurations of actors, technologies, and relationships within and beyond the household (Blunt, 2005; Head and Muir, 2007; Kaïka, 2005). This thinking offers an alternative to conventional cause and effect approaches. Instead of looking for single root causes of problems, we can understand the world as built of complex relations of things and processes, including householders' experiences of technologies. For instance, the type of SHW system installed, how it is installed, where it is installed, the weather, and the water temperature are entwined with the beliefs and practices of householders (themselves demographically and culturally diverse), alongside the design, materials, visibility, and accessibility of energy-saving websites, collector plates, timers and electrical switches and so on. Such thinking helps identify when and how social and cultural norms, such as cleanliness norms that have developed in concert with modern systems of provision that seamlessly deliver water and energy to households (Shove, 2003), constrain or enable energy efficiency practices. It provides opportunities for analyzing individual actions and responses for potential policy intervention points.

In considering our empirical material we discovered particular behaviors and beliefs that worked to either enhance or constrain energy efficiency. they included such things as monitoring the weather and electricity bills, use of booster switches, knowledge of electricity tariffs, expectations around installation, water temperature, ease of use, and household temporal rhythms. These we group into two main categories first emerge from zones of friction where we observed 'pathways of resistance to more sustainable outcomes, or contradictory practices that entrench less sustainable outcomes' (Head et al., 2013, p. 6). The second emerged from zones of traction, where practices develop or existing practices are creatively unsettled such that more sustainable outcomes are likely (Head et al., 2013). Both zones potentially help to identify useful and possibly unexpected, points of intervention to reduce energy use. We thereby gain insight into how different elements of systems of provision, the material elements of homes and their operation, and everyday practice interact in the context of the household to influence the efficacy of SHW installation and use. Sources of traction and friction are identified and summarized in the results section.

1.1.2. Solar hot water (SHW) and the sustainable household

A limited number of studies have focused on the nexus of environmental policy, household sustainability and SHW systems. A key finding has been that households are frequently deterred by the initial high costs of installation and esthetics of SHW systems (Faiers and Neame, 2006; Sidiras and Koukios, 2004; Tombari, 2005). For example Grieve et al. (2012) found in a small-scale study in New Zealand that, despite promotion and strong consumer support for renewable energy use, high levels of inertia prevented SHW system purchases. Cultural factors such as a desire to support local jobs and industry can also strongly influence decisions to purchase and install SHW systems (Kwan, 2012; Li et al., 2011; Ma et al., 2014).

In keeping with our conceptual approach, we consider the complex ways that SHW technology becomes integrated or not, into social practices and accordingly generates uneven, unintended and sometimes negative feedback loop effects. For example, contrary to the assumption that increasing awareness of energy consumption will drive households to lower usage, technologies that help consumers to monitor their electricity consumption have been shown to have limited results. Strengers (2011) illustrated how the utilization of smart meters did not unsettle those practices which householders considered non-negotiable (see also Oltra et al., 2013). Likewise, installing water-saving tanks does not always lead to predicted reductions in water use (Moy, 2012), and SHW systems have not always delivered expected energy efficiencies. Our research identifies such difficulties and obstacles with SHW systems. Before exploring results, we first provide a discussion on the types of SHW systems available to consumers, and how they link users to existing systems of provision.

1.1.3. Solar hot water technologies and systems of provision

Systems of provision – the assemblages that connect people with sites and technologies of production, distribution and consumption (Fine and Leopold, 1993) – may be fixed or fluid. Where they are fixed there is little opportunity for households to make substantial changes themselves. Switching to a SHW is one means of providing consumers greater autonomy from the fixed energy systems through electricity and gas networks. The extent of this autonomy is limited, however, by the complexities associated with the process of selection and operation of SHW systems.

There are a variety of SHW products on the market which largely fall into one of two categories – split systems and close-coupled systems (Department of Industry and Science, 2013; Harris, 2011). Split systems (Fig. 1) incorporate a solar collector panel on the roof and a tank at ground level and require the use of a pump to move water from the panel (where it is heated) down to the storage tank. Collector panels are either flat plates (the most common and cheapest solar collector on the market), or evacuated

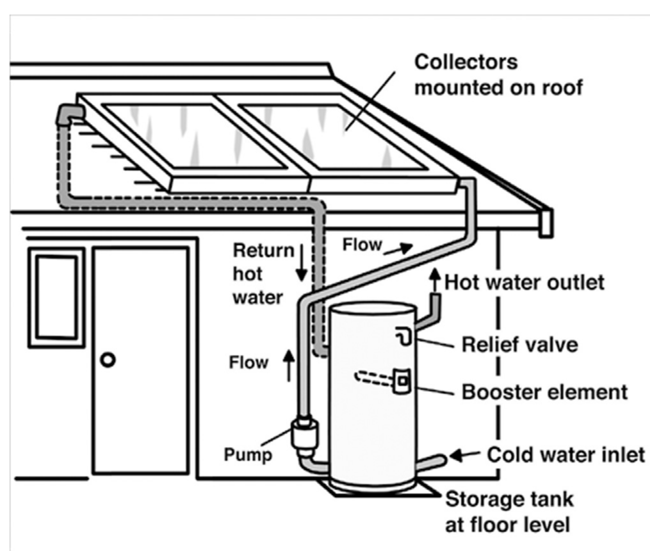

Fig. 1. Example of a split system installation (diagram cc-by Department of Industry and Science, 2013).

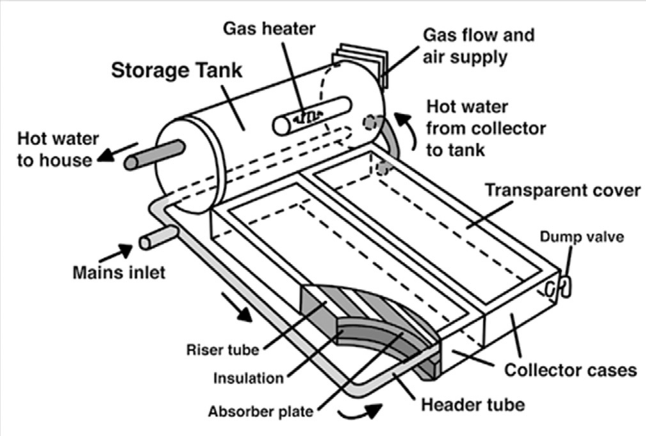

Fig. 2. Example of a close-coupled or thermosiphon system installation (diagram cc-by Department of Industry and Science, 2013).

tubes, which are relatively efficient but also more expensive. The second type of SHW system is a close-coupled or thermosiphon system (Fig. 2), whereby both the collector panel and storage tank are located together in the one unit on the roof.

These latter systems do not require the use of a pump as water usually operates under mains pressure and is circulated from the tank to the collectors and back into the tank by natural convection. This system is the cheapest and easiest system to install. In both split and close-coupled systems a booster provides additional heating in the tank when temperatures drop below a set level controlled by a thermostat. This is achieved through either an electric element or a gas burner. Storage systems can be installed with a booster override switch, facilitating greater householder control. Another variation of boosting is a gas instantaneous booster that is attached to the output of the storage tank and boosts the water through the outlet when necessary (Clean Energy Council, 2011; Harris, 2011).

A number of studies indicate that the efficacy of SHW systems is largely dependent on factors including storage tank size and placement, the size and composite material of the collector panels, and the level of insulation on pipes and tanks (Clean Energy Council, 2011; Energy Saving Trust, 2011; Harris, 2011). These factors influence the ability of the system to heat water and maintain temperature. This in turn affects the frequency and extent of boosting required. The type of booster installed and the extent of use directly affect the capacity of the system to reduce household emissions and energy costs. SHW systems therefore, to some extent, allow individual householders to manage their hot water production independently of mains energy supplies, yet the requirement to boost means these systems are still partially reliant on external systems of energy provision. SHW systems therefore represent a hybrid of both fixed and fluid systems of provision.

Boosting is a conceptually straightforward response to declines in the capacity of a SHW system to produce sufficient hot water to meet household demands during periods of cold or cloudy weather. In practice, however, boosting entails a degree of complexity that consumers must comprehend if they wish to maximize efficiency, particularly if they use electric elements. In such cases households are subject to another fixed system of provision, namely the tariff system. Electricity demand is managed through pricing mechanisms, known as tariffs, which attempt to spread demand for electricity across a 24-h cycle. The most commonly used tariff system is a combination of a single or domestic rate tariff, used throughout the day for the majority of domestic power usage, coupled with an off-peak tariff, metered separately and time controlled to only operate during low demand periods (Australian Energy Regulator, 2013). In most cases the off-peak meter is used exclusively for household hot water systems, usually between 9 pm and 7 am. For electric-boosted SHW systems, this means that boosting can only occur overnight. As we elaborate below, such fixed systems of provision intersect with everyday household practice in complex ways that directly impact SHW system efficiency, and therefore households' ability to minimize carbon emissions.

1.1.4. Everyday and embodied practices of SHW systems

The relationship between the timing of boosting and everyday household patterns of hot water use are crucial factors influencing SHW system efficacy. This is likely to be particularly the case in temperate regions such as for our study area. If the majority of household members shower at night, then the storage tank will be drained of hot water. This will trigger the booster to come on, heating the water overnight and effectively making the solar panel redundant the next morning. For this reason it is recommended that all boosting occur immediately prior to the peak usage period in order to 'top up' the work already done by the SHW system (Harris, 2011). This can be achieved in systems attached to a gas booster through the use of an override switch that allows residents to control the amount and timing of boosting. In the case of electric boosted systems, however, the ability to control the timing of boosting can be constrained by the tariff system. In this situation there are very few options for users to control the amount of boosting their system uses, apart from modifying use patterns or changing their tariff system. In summer, boosting may not be required to heat water and switching the booster off will ensure that the SHW system is allowed to operate to its full potential. However during periods of cold overnight temperatures or overcast weather, switching off the booster is likely to compromise the availability of hot water for use during the day, with no opportunity to boost until late in the evening. Further, at least occasional boosting is also required to sterilize the system. Switching to a 'time of use' tariff system that charges different rates at different times of day, means that cost savings from the SHW system may be compromised given that daytime boosting will be charged at a higher peak rate (Australian Energy Regulator, 2013).

Responses to energy efficiency programs are often characterised by individual conceptions of 'negotiable' and 'non-negotiable' adaptions to resource use (Strengers, 2011). Studies into the use of smart meters, for example, found that people were willing to adapt their behaviour and use of electricity to a certain level, such as by switching off lights and turning appliances off at the wall. They provided, however, minimal impetus to behavioral changes relating to over-riding consumer 'needs', such as showering and laundering, which are often associated with constantly evolving notions of cleanliness and hygiene (Shove, 2003; Waitt, 2013). The installation of a SHW system may therefore represent a challenge for households who may need to trade off their energy efficiency expectations against their desire to maintain inefficient patterns of usage. The combination of the many different technical aspects of managing a SHW system means that what appears, on face value, to be a simple measure to curb household emissions is in fact a highly complex dilemma that challenges the notion that it is 'easy to be green' (Gibson et al., 2013).

In light of this we now turn to our empirical material. This evidence illustrates how systems of provision, social practices, motivations, expectations, technologies and everyday practices interact to influence the use and efficiency of SHW systems.

2. Methods

The empirical material presented here is drawn from a sustainability project conducted in temperate Australia. Most participants were initially respondents to a postal survey concerning household sustainability (Waitt et al., 2012) who had both installed SHW systems and indicated their willingness to participate in a follow-up interview. Others were recruited via snowballing from these survey respondents and through personal contacts. Interviews were conducted with an adult decision-maker in twenty households who had installed solar hot water systems in their residence. The interviewees all owned the houses they lived in (or had mortgages on them), were aged from their thirties to their seventies, were from various socio-economic backgrounds (including one pensioner), and included single member households, couples, and families with children (Table 1). Participating households had among them the full range of SHW systems on the market including thermosiphon roof top systems, split gas and electric systems as well as one heat pump. We inspected each SHW installation and recorded attributes such as the type of system, tank capacity, the number of panels, whether they were gas or electric boosted, whether they had a booster switch, insulation quality, and the tariff system being used. Where possible we obtained energy bills and, in conjunction with a census of major household appliances and electrical goods and their patterns of use, we were able to use this to calculate household energy use for nine interviewees and thereby estimate SHW system effectiveness.

Interviews were audio-recorded and on average were 60 min long. They were transcribed verbatim. Nvivo 9 qualitative analysis software was used to code, sort and categorise key interview themes (Saldana, 2009). This initially involved basic descriptive level coding, followed by progressively categorising and sorting key concepts and ideas to determine patterns within the data (Saldana, 2009). Dominant themes from this analysis were the most frequent coding references. These structure our results and discussion below. We acknowledge that as a localized and relatively small scale qualitative study this project has limited generalizable results. While the sample included a range of household configurations, occupations, ages and a range of SHW systems in use, the results may not be representative of all users, SHW systems, or regions. Nevertheless the sample size, typical for cultural methodologies of this sort (e.g. Moy 2012; Hitchings et al. 2015), does provide adequate rich insights into the benefits or challenges associated with this technology.

Table 1
Selected interviewee and solar hot water system characteristics (the thermosiphon systems were all electricity boosted; see Section 1.1.3 and Figs. 1 and 2 for descriptions of these two types).

Active or passive	Age	Number of occupants	Dependent children	Insulation quality	System
Active	35–44	4	2	Adequate	Thermosiphon
Active	35–44	5	3	Poor	Electric split
Active	45–64	3	1	Unknown	Split gas
Active	35–44	4	2	none	Thermosiphon
Active	65+	2	0	none	Split gas
Active	35–44	7	5	Adequate	Thermosiphon
Active	35–44	4	2	Poor	Thermosiphon
Active	65+	4	1	Poor	Thermosiphon
Active	35–44	4	2	Adequate	Thermosiphon
Active	65+	2	0	Poor	Thermosiphon
Active	45–64	2	0	Poor	Thermosiphon
Passive	35–44	4	2	Poor	Thermosiphon
Passive	65+	1	0	Poor	Electric split
Passive	35–44	2–5	2	Unknown	Thermosiphon
Passive	35–44	1	0	Poor	Thermosiphon
Passive	35–64	1	0	Unknown	Thermosiphon
Passive	35–44	2	1	Poor	Electric split
Passive	65+	1	0	Unknown	Thermosiphon
Passive	35–44	1	0	Poor	Air sourced heat pump
Passive	35–44	2	0	Poor	Split gas

3. Results and discussion

3.1. Modes of operation: managing the SHW system

Results revealed that participants were either active or passive users of their SHW system. The distinction between active and passive users marked a clear differentiation of concerns and attitudes towards the SHW system. Satisfaction with the system and its effectiveness was also critical. Participants frequently discussed the work involved in managing and monitoring system use, and difficulties in understanding exactly how it operated. Many had required varying levels of experimentation and active management in order to achieve an acceptable outcome:

> *Experimenting and then finding that we don't have hot water in the morning is a pain in the butt. So you try not to, it's not an experiment that has kind of the neutral result to it. So we did it just for a very, very short time…We didn't know what it was actually doing, we didn't want to not have the hot water, okay we do want to stop our carbon footprint, but we have to face it, to be honest, we don't want to not have hot showers.*
> *(Male, 35–44, couple with dependent children, active)*

Friction was evident where nine participants had given up on early attempts to determine the best means of operating their system. Traction was evident where eleven remained actively engaged in its management – either by switching the booster on or off, monitoring its performance or, less frequently, adapting their use of hot water to suit the system. These eleven participants undertook active SHW management regardless of the system they had installed, yet only one was satisfied. Complaints ranged from system installation to operation. These indicate further sources of friction. Examples of this are discussed below (in sections 3.3 and 3.4). One person, an active user, was dissatisfied due to the installation location and had even pursued the issue with the state consumer law agency.

The remaining nine who were passive users and not actively engaged with the system, were ambivalent to or unaware of its performance, apart from its provision of hot water, and had not adapted their water use in response to the system's installation. In such case friction took a passive form, with users largely treating their SHW as background household infrastructure. They treated SHW as if it were a conventional hot water heater powered by mains energy sources, and expected it to deliver hot water on demand regardless of circumstances or use. Relatively high levels of boosting are likely to be required to meet such expectations. Four of nine passive users expressed satisfaction with their systems: they felt satisfied that the system was meeting their hot water needs and beyond this had given little further thought to its operation. For example, one participant said:

> *to me the point of a utility is that I don't have to think about it. I just want it to be invisible. As long as it's invisible, I'm happy (Female, 35–44, couple only).*

Friction thus itself takes both active and passive forms.

3.2. Motivations, perceived effectiveness and satisfaction

Seventeen out of the twenty participants listed financial motivations for purchasing their SHW system. Key moments of traction provided evidence of 'inadvertent environmentalisms' (Hitchings et al., 2013), in that the decision to install a solar hot water system was generally triggered by the need to replace an old system (11) or a major change in the life of the participants (6) such as the construction or purchase of a new house, renovations, retirement or the birth of children. Nevertheless the decision

Table 2
Techniques for active management or experimentation with solar hot water system, including number of participants and example quotes.

Experimentation/ active management techniques	No.	Example quotes
Switching booster on and off	11	*So it's a bit of a hit and miss affair, you know? Sometimes I'd be boosting when I didn't have to, and then others I wouldn't boost and after we'd have a cold shower at night. (Male, 45–64, couple only)* *..I wash the dishes at 9:30, 10:00[pm] and if there's not enough hot water then to make you feel comfortable doing the dishes, well then switch it on otherwise we'll be freezing under the shower, which is not a good start to the day.(Female, 65+, couple only)*
Technical adaptions (adjusting thermostat, adding timers etc.)	7	*It's certainly working a lot better since we got the thermostat put up. (Female, 35–44, couple with dependent children)*
Tariffs (consideration of tariff options, such as changing to Off Peak 2 or domestic)	6	*So then I just went off peak two. And that means now I get two goes at it in any one day. Now that I am home a lot of the time during the day I actually can put it on before 4:00. (Male, 45–64, couple only)*
Booster switch added or moved inside	3	*We also got a switch for the booster located in the house. So it used to be at the box outside. So you have to go outside. (Female, 35–44, couple with dependent children)*

to choose solar over other water heating methods was commonly accompanied by environmental concerns. Environmental motivations featured as traction in the interviews to varying degrees (either as a primary motivation or one of mixture of different motivations), including amongst passive users. Only three of the participants interviewed focused primarily on economic gain or government incentives in their descriptions of why they chose to purchase a solar system. Six participants, including four passive users, were attracted by the green credentials of SHW systems, and wished to 'set an example' or to be part of a community-wide effort to improve sustainability:

> *I mean, I believe in leadership, and it's more about changing the world, and doing, you know, Gandhi's philosophy of being what you want to change, you know? (Female, 35–44, couple with dependent children, active user)*

Personal motivations to 'feel good', to lead by example, or to feel like they were making a difference, were strong sources of traction.

However, the overwhelming response from participants in relation to SHW system effectiveness in reducing electricity consumption or power bills was one of confusion and uncertainty. While confusion was not limited to passive users, it was significant that all nine passive users indicated they were unsure of whether they had made any financial or energy savings. This was often due to being unsure how to best monitor usage, but there was also a sense of confusion about how to factor in the energy costs of measures required to manage the system. These variables included the booster, pumps and adjustments to the thermostat, as well as changes in energy consumption, price or type (gas versus electricity) over time. Such uncertainty represented a form of friction, as there is no clear feedback relating to financial and/or environmental motivations for installing SHW.

Of those active users who had monitored consumption following system installation, all reported a decrease in consumption and thus traction; however many emphasized that this was due to their management of the system. In addition, since many had switched to solar from cheap off-peak electric hot water heaters, they did not believe the SHW system had resulted in significant economic savings through lower power bills. Six participants (three active, three passive) did believe they were making economic savings, but this perception was based on rough estimates rather than accurate monitoring.

While tracking actual consumption rates was not possible for all interview participants, they were successfully recorded for nine participants using utility bills provided by interviewees. Of these, two had systems that could be classified as operating 'effectively' (electricity consumption of <1 kWh/person/day). The remainder were considered to be operating ineffectively (>2.5 kWh/person/day) or only moderately effectively (1–2 kWh/person/day). Five of these two latter groups were passive users, supporting the proposition that active management can be an important factor in achieving maximum energy efficiency outcomes. In addition, two of those five participants who were satisfied with their system were classified as operating less than effective systems. However, despite their active SHW system management, only one of the active users had a demonstrably effective system. Of the other two active users for whom we have energy consumption data, one was classified as operating ineffectively and one as moderately effectively. Such findings, though inconclusive, trouble assumptions of active management and maximum energy efficiency outcomes. It seems that active management has the potential to be a source of traction but that this is not being fully realised. Other sources of friction intervene, possibly related to 'meshing' water use habits, system operation, and weather. This suggests the value of more detailed research into active management strategies, their characteristics, their place in household processes, and their measured effectiveness.

3.3. Decisions, advice and installation

For a number of active users substantial effort was made to maximize their independence from the fixed systems of provision of gas and coal-powered electricity. For many, however, the continued level of reliance on conventional energy providers came as a surprise, and a range of strategies were developed to work around this (Table 2).

A substantial source of friction in reducing energy use was a lack of understanding of how the system worked and how it was influenced by daily use patterns. Confusion or lack of awareness over particular aspects of SHW system functioning featured in more than half (13) the interviews, including eight of the nine passive users. A number of the research participants were highly-educated and informed individuals who were nonetheless confounded by the level of complexity involved in choosing, installing and operating the systems as well as the multiple types of rebates and regulatory incentives involved in the process:

> *I realize that there is absolutely no way most people would be able to find their way through this minefield, you know…and most people don't have the wherewithal to do that, I don't think, you know? I find it difficult enough… I have a PhD; I should be able to do these things! (Female, 65+, couple only, active user)*

Due to such complexities, participants were often reliant on installers for provision of advice over the type of system to install and where to install it. Access to unbiased information from a trusted source was often raised as a key concern:

the first guy didn't know what he was talking about, really. I knew probably more, and I thought, you're really trained in selling this based on the rebate, and you are a salesperson. (Male, 35–44, couple with dependent children, active user)

For some participants, points of traction were opportunities to obtain independent advice or at least a range of opinions from different suppliers at trade fairs, regional shows or locally and community run sustainability initiatives, such as the "Sustainable Illawarra Community Challenge" and "Jamberoo Future Care". These events appeared to have significantly increased participants' engagement in researching the most efficient product for their situation. One participant said:

A Jamberoo FutureCare guy did a separate talk off in a side room, which was good because it was, sort of, non-biased. So, he talked, just about solar hot water and all the issues…the tempering valves and…insulating the pipes.
(Male, 35–44, couple with dependent children, active user)

Concerns about finding trusted sources of knowledge and expertize also extended past the decision making process. Potential and observed sources of friction were evident in a number of participants' concerns about the installation process and in our observations of installation. These sources of friction often related to a lack of knowledge or forethought by installers about the best means of installing the product to ensure maximum efficiency, or taking shortcuts in the installation process (Table 3) – shortcuts that we commonly observed ourselves when conducting interviews. Observed installation shortcomings included solar panels shaded by trees, solar panels facing in the wrong direction, lack of proper insulation, tanks or panels that were undersized, water pipes that were sub-optimally routed or positioned, and panels supported on vulnerable structures. Only three of our participants' SHW installations had insulation that we judged to be at least adequate (Table 1).

Friction further arose where expectations about shifting to more sustainable lifestyles were frustrated. Many of the participants expressed a range of complaints about the operation of the systems after installation, challenging the notion that the systems were an 'easy' means of reducing consumption (Table 4). While desires to reduce energy use can facilitate traction in encouraging people to install SHW, some felt that the SHW system had forced them to compromise on other sustainability objectives, particularly water efficiency, for example,

…it leaks a lot. And I don't care about a little dribble of water, but it…gnaws at me a little bit that it's wasting water in some way… they have said that this is what happens, it has this overflow thing happening. And they said it will happen every now and again, but it actually happens a lot more than every now and again. (Male, 35-44, couple with dependent children, active)

Half of participants Perceived that their water consumption had increased due to such loss from the overflow valve or due the distance between the tank and taps.

3.4. Everyday practice

Environmental motivations are clearly a point of traction driving adoption of SHW systems. This research reveals that SHW systems appeal to people's sense of'environmental citizenship'. However, such environmental motivations do not always translate into active management and monitoring of consumption levels. This suggests a 'blind faith' and a source of potential friction, especially amongst passive users, that the system was achieving the promised environmental outcomes. An example of this was one passive user, who took considerable personal pleasure from the feeling that she was reducing her carbon footprint but whose system (as we determined from her utility records) was operating at a highly ineffective level:

I think I just enjoy using it more because when it kicks in I think the sun is doing this and now you're telling me that this is the electric boosters doing this…but no, I haven't changed anything. I just feel smug. I enjoy feeling smug. (Female, 35–44, single person household)

She and other users, both active and passive, were working to a conceptual 'sustainability checklist' promoted and encouraged as part of green consumerism (Diaz-Rainey and Ashton, 2011) and supported by government incentives such as rebates and carbon credits. These include water tanks, photovoltaic systems, energy saving light globes, water saving devices and vegetable gardens. These were often viewed as 'easy' ways of improving environmental footprint, made easier by the provision of Government funds to assist in purchase price of the more expensive infrastructure.

While some participants chose to modify their use of the system to work around its shortcomings, or had experimented with timing showers at different times of the day, overall most (17) participants had made very little or no changes to their use of hot water:

Table 3
Concerns about installation and maintenance of the SHW system.

Installation/maintenance concern	No.	Example quotes
Problems with location: concerns over the system being placed in the wrong location. Alternatively space or other practical issues forced compromise in location or type of system	12	*And in retrospect I should have…had the tank on the side of house. It would have been easier for the shorter range of pipe work. That's just because I thought they'd run the pipe work down by the side…I was very ticked off with their installation procedure. (Female, 35–44, single person household, passive)*
Maintenance or repairs required: adjustment of thermostat, repair of faults or problems.	11	*I realised that the gas was cutting in and staying on, and somebody had to come back and reset the thermostat… But we, we had to be aware of that ourselves and get them back. (Female, 65+, couple only, active)*
Inadequacies in installation: faulty workmanship, incorrect placement, inadequate insulation	8	*they installed on the wrong facing roof…we had to argue with them to get it moved to the correct one, they gave us misinformation saying it was going to be fine on the east facing part of the roof. (Female, 35–44, couple with dependent children, active)*

Table 4
Sources of dissatisfaction with solar hot water system, including number of complainants and example quotes.

Common complaints	No	Example quotes
Labor intensive: requires active management	14	*..every morning I have to get up and I have to guess, to get a warm shower at night, I have to guess what the day is going to be. So I became a real weather watcher. (Male, 45–64, couple only, active)* *I go and turn it on, and then I forget I've turned it on. (Female, 65+, single person household, passive)*
Variable heat: water not hot enough according to weather/season, heat lost overnight or on cold days, or through lack of insulation.	13	*It doesn't heat the water up sufficiently in the wintertime. Our temperature in this area is not strong enough in the wintertime to maintain hot water. (Male, 65+, three adults, dependent child, active)* *but a day of heating followed by cold day, and I had cold water. And it was uncomfortably cool…I was really frustrated by that stage. (Male, 45–64, couple only, active)*
Water used increased: perception that use of water has increased due to time lag in hot water coming through or through loss of water through overflow valve.	10	*And it leaks a lot. And I, I don't care about a little dribble of water, but it…gnaws at me a little bit that it's wasting water in some way… they have said that this is what happens, it has this overflow thing happening. And they said it will happen every now and again, but it actually happens a lot more than every now and again. (Male, 35–44, couple with dependent children, active)*
Booster operating excessively – booster coming on too frequently or for too long	7	*And it was a bit of confusion when we first got it on, because I was going, it's ridiculous to have the solar hot water and every time the, you know, we just turn the tap on to – to wash your hands, and then the gas comes on and it stays on for quite a while. (Female, 45–64, couple with dependent child, active)* *It seemed that there was an issue with the timing of the drawing of hot water and heating it by the sun. It seemed like you were always trying to heat a pretty warm tank to begin with. (Male, 35–44, couple with dependent children, active)*
Conflict between efficiency measures – efficiency gains from SHW offset by other losses e.g. increased water use, need to remove trees etc.	5	*And it seemed to me that rather than throwing out the embodied energy of the tank that works and is fine, but they insisted I had to get a tank and everything. (Male, 35–44, couple with dependent children, active)* *I had to make some decisions but my environmental friends said you're not going to cut your trees, you're going to keep your trees. (Female, 35–44, single person household, passive)*

> *I wash the dishes at 9:30, 10:00[pm] and if there's not enough hot water then to make you feel comfortable doing the dishes, well then switch it on. Otherwise we'll be freezing under the shower, which is not a good start to the day.*
> *(Female, 65+, couple only)*

Most concentrated efforts on technical adjustments to the operation of the system rather than behaviour modification (Table 5). A large number of participants did profess an increased level of awareness or knowledge about sustainability issues, perhaps partially stimulated by the installation of the SHW system, which for many had translated into traction via active monitoring of consumption patterns and the weather. Some, despite early attempts at modifying their use or controlling the operation of the system had simply given up any efforts to manage the system proactively.

On the whole, passive users had largely undertaken minimal, if any, active monitoring of their consumption levels, usually involving little more than a cursory glance at electricity bills, which in turn often led to concerns over the best means and ease of interpreting or comparing these bills. Busy lifestyles and a lack of technical understanding of the way in which systems operate led to ambivalence or ignorance of the value of active monitoring. Passive users were the consumers most satisfied with the product. They were only dissatisfied when their ability to 'set and forget' was interrupted by a loss in quality or quantity of hot water or efficiency. Therefore, their ability to treat a SHW system as background infrastructure was a strong influence on their level of satisfaction with it, suggesting a zone of friction which may cause resistance to active engagement with their systems. While a lack of knowledge and awareness around the need to actively manage SHW systems was identified as a potential obstacle to efficacy, the research also identified useful means of providing better information to consumers. Community events as well as informal networks of friends and families are important sources of traction, which can empower consumers through the provision of advice from independent and trusted sources.

In most cases (17) the participants reported little if any explanation from installers about how to operate the system to ensure energy use reductions were maximized. Therefore it appears that the majority of the passive users felt their contribution to achieving an energy efficient heating system for their water ended with the installation of the SHW system. This is likely to have been encouraged to some extent by a public discourse that suggests it's 'easy' to be green, with government incentives essentially providing endorsement of particular methods of reducing energy consumption with very little impost on the consumer.

Finally, the results of this research clearly indicate most participants felt there was little room for negotiation around timing, length or frequency of showers in their everyday lives. Rather, they focused energies on other means of adaptation to the requirements of their system (such as boosting), or completely disengaged from the system altogether and allowed it to manage itself regardless of any associated declines in efficiency outcomes. Participants mentioned their smell and levels of sweat as indicators of the need to shower frequently, concurring with recent research on social norms of cleanliness and bodily hygiene as zones of friction and traction (Waitt, 2013). As well, families with teenage children commented on their tendency to shower more frequently or for longer periods. This general reluctance points to a zone of friction whereby maintaining and even increasing standards of personal

Table 5
Behaviour modification as a result of the SHW system.

Behavioural responses to the SHW system	Active	Passive	Example quotes
Little or no changes to use of hot water, including shower times, length or frequency	9	8	*Our household water wise, hot and/or cold is behaving as it was before as now, so it is exactly as we wanted it to be. (Male, 35–44, couple with dependent children, passive)*
Increased knowledge or awareness (research and examination of ways of reducing consumption or increasing efficiency)	9	6	*You've only got to have the heater on, a 1500 heater on for an hour, and you've got one half kilowatt spread on. We're only using now less than 7 a day total, absolute total. There's probably very few households who are using that little power. (Male, 45–64, couple only, active)*
Monitoring consumption (increased awareness of consumption patterns)	6	3	*When we first got it, I did do it…We looked at bills before and bills after. And, essentially it made bugger all difference. (Female, 35–44, couple with dependent children, active)* *I do know it saved me 30 bucks a quarter…And I think I compared it to the previous year's bill. Not just the previous quarter…So I knew it was 30 bucks direct saving. Not just a seasonally adjusted figure. (Female, 35–44, single person household, passive)*
Monitoring weather (increased awareness of the weather)	6	0	*We, it feels like we have to second guess what the weather's going to be like. So we have to understand then what the weather is today, tomorrow for whether we put the booster on tonight. (Female, 35–44, couple with dependent children, active)*
Modification of use (e.g. experiments with different shower times/ length)	8	1	*But we time it. So I now have to wait till 2:00 until it's heated up. I'm happy to do that, though. (Female, 35–44, couple with dependent children, active)* *So I tried to train him to have a shower in the evening when he came instead of in the morning. (Female, 35–44, couple with dependent children, active)*
Giving up (too hard, just leave booster on full time or for entire winter)	4	1	*Experimenting and then finding that we don't have hot water in the morning is a pain in the butt. So you try not to, it's not an experiment that has kind of the neutral result to it. So we did it just for a very, very short time…We didn't know what it was actually doing, we didn't want to not have the hot water, okay we do want to stop our carbon footprint, but we have to face it, to be honest, we don't want to not have hot showers. (Male, 35–44, couple with dependent children, active)*

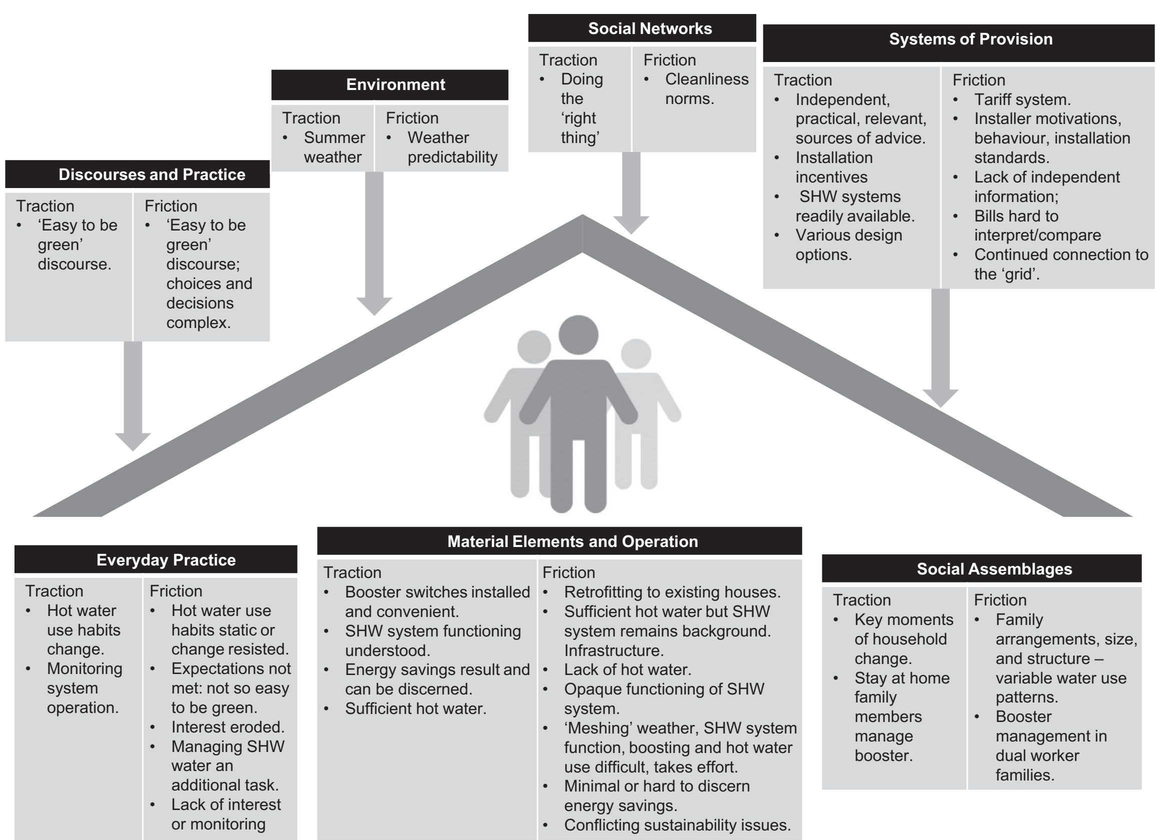

Fig. 3. Zones of friction and traction in solar hot water system installation and use.

hygiene inhibit energy use reductions. Indeed, in parallel to how water tanks provide water that householders regard as theirs to use as they see fit (Moy, 2012), the motivations detailed previously to 'feel good' may undermine sustainability outcomes by providing SHW users the option of 'guilt free' showers.

4. Conclusion and policy implications

This paper has outlined how post-installation outcomes of SHW system installation and operation are multi-faceted and diverge between active and passive users. Building on cultural approaches and thinking about households in relational terms, we have discussed how inter-dependent systems of energy and technology provision, incentive schemes, the design and material elements of SHW systems, the houses into which they are installed, and everyday practice coalesce. We identified challenges faced by households, installers and governments in building adaptive capacities, achieving energy efficiency outcomes and integrating technologies into social systems.

People, technologies and policies are interdependent and interwoven. Disentangling these pointed to zones of traction and friction in our discussion and throughout examples in tables two to five that influence energy use outcomes associated with SHW systems (as summarised in Fig. 3). We provided examples of the way that installation and management of SHW systems proved problematic even for households committed to reducing energy use. For example, while government incentives acted as a source of traction, in encouraging the adoption of products aimed at improving household sustainability, they also resulted in potential zones of friction. In the case of the passive users in this study there was a sense of the installation of a SHW system as an 'end' unto itself, rather than a means to reduce household consumption. Householders may assume their SHW system is working well when it is not. Combined with a lack of information or knowledge needed to monitor what is a complex system, this acted as a zone of friction. Even among active users, struggles to operate SHW systems and integrate them into household routines acted to erode engagement, generating friction. The end result in both cases is that gas and electricity can continue to be used to heat water in excess of householders' and policy expectations.

This has several key policy implications. First, is the need for a broader assessment of national SHW programs. The problems with installation and use identified in this paper are consistent with previous research in Australia (Miller and Buys, 2010) and elsewhere (Energy Saving Trust, 2011; Giglio et al., 2014). Thus far there has been no systematic assessment, and uptake of solar hot water technology, although growing, remains low as a proportion of the national population (15% of all Australian households, Osman, 2015). We provide further evidence that a policy review is urgently needed. Both SHW system installation and use may need significant improvement to ensure that incentive funding is being used effectively to achieve policy goals. The assessment of current policy and programs that we recommend should usefully expand upon existing Australian case studies and qualitative research, including that reported here, to gain insight into SHW installation and use at a broader scale. It should systematically measure SHW system performance and assess this in light of household characteristics, management style, hot water use patterns, as well as installation processes, characteristics, and quality.

Second, while the National Hot Water Strategy has been designed to ensure that Australians have 'access to clear and consistent information on energy efficient products and services' (Council of Australian Governments, 2010, p. 11), we suggest that further research is required to determine how this element of policy shapes energy efficiency outcomes. Given the difficulties some of our interviewees experienced around installation advice, it is possible that this constitutes a barrier to installation in that lack of trust and uncertainty regarding matching installation to a particular house may militate against a decision to install SHW. Further, even if households were aware of the utility of installation advice, interviewees appeared to have no clear and trusted sources of advice regarding the ongoing use of their SHW systems. This invites a constructive future policy discussion around mechanisms to improve installation advice and access to it. Third, the research identified significant levels of dissatisfaction with technical advice and the quality of installation provided by installers, coupled with our own observations of poor installation. Participants generally found themselves left without guidance from installers on using SHW systems, suggesting, charitably, that installers subscribe to the idea of the system being an end in itself, or less charitably, that they are cutting costs in a competitive market by not expending time and materials on instructions and guidance. Further research (and accompanying policy development) is needed to determine what objectives installers try to achieve on behalf of both themselves and their clients through the installation of SHW systems. Why does quality of installation vary so much? How do installers manage the idiosyncrasies of installation in existing houses, and handle any tradeoffs or compromises that may be required? To what extent might installation reflect excessive prioritization of hot water supply over other considerations? In addition, how installers 'sell' the product to the clients, whether through the marketing of personal benefits, cost savings, or ease of use deserves further investigation and policy response.

A range of technical issues regarding SHW installation also requires closer examination (Osman, 2015). Inadequately sized installations can result in negligible benefits for households with high occupancy, yet there are limits placed on SHW system size in current incentive schemes. Why are heat pumps so under-represented in areas where they are likely to be relatively effective, for example in NSW coastal communities that have significant periods of cloud cover? Why are installation rates of low-emission water heaters negligible in apartments and home units? The answers to such questions will broaden current knowledge beyond the quality of installation and household SHW use, to the nature of the supply chain, to the motivations and practices of installers, and to their role in the energy efficiency outcomes of publicly-subsidized SHW policy and programs.

Fourth, and more positively, we identify that failure of an existing system, changes in life stage, or major events such as house renovation are potentially key moments of traction, of 'inadvertent environmentalism' (Hitchings et al., 2013) in which installing a SHW system is likely to be considered. This suggests target opportunities for policy and programs. Encouragement or incentives to plan ahead for SHW installation ought to aim to militate against such events becoming points of friction. At a time of system failure or at a moment of change, which might otherwise be stressful, more targeted programs could ensure that switching to a SHW system is a straightforward and relatively affordable option.

Finally, and most germane to the cultural lens that we have applied, is the need for a shift in policy thinking to see installation as but one part of a longer process that sees householders engaging with SHW systems and various actors both before and following installation. Maximizing efficiency gains requires recognition of this and greater attention to what happens post-installation. Far from representing the straightforward beginning of ready supplies of cheap, solar-heated water, installation represents a point at which the SHW itself becomes caught up in the norms, expectations, practices, and habits of the household. This marks a point at which households might be supported to experiment with combinations of water use timing, booster operation and to develop new habits that incorporate the contingencies of weather, household processes, and SHW system operation.

We have illustrated that the installation of SHW systems as an easy, technological fix to reducing household carbon emissions is in practice a complex negotiation of ideas, practices and understandings that can have contradictory outcomes. Our findings suggest that long term policies and programs that are in place to reduce emissions in the heating of household hot water face substantial cultural impediments and the risk of less than optimum outcomes. Through identifying active and passive users of the technology, we have given insights into the challenges of achieving effective energy use reductions and highlighted the need to think and act beyond rational choice models of the household in policy and programs. By employing from cultural research the conceptual model of zones of traction and friction, we hope to stimulate further investigation and research into how systems of provision, the material elements of homes, and practice intersect around energy efficient technologies in the interests of reducing household carbon emissions.

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