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Solar Water Heating: Informing Decarbonization Policy by Listening to the Users

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Introduction[1]

Governments planning to decarbonize energy systems count not only on transforming energy supply but also on changing what technologies are used in daily life, not just by the eager but by tens of millions of users. The research approaches needed to gain sufficient understanding of these

[1]Passages in this chapter were written by Hal Wilhite as notes over the course of the research project. These notes were repurposed for this chapter. Hal conducted many of the interviews. He did not have the opportunity to review or add to the manuscript.

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users and uses to translate their real-world messiness to successful decarbonization policy planning are underdeveloped. This chapter reports on a humanizing element of a technology research project that was undertaken to inform a state energy agency on the prospects for expanding the use of solar thermal water heating in California homes. Currently, solar thermal water heating is used by fewer than 0.5% of households in the state, despite favourable environmental conditions and the popularity (14% of homes) of rooftop photovoltaic (PV) systems (CEC, 2021).[1]

Solar water heating is essentially an old technology, common for decades in some areas of the world, with active attention to increasing its use in others (Weiss & Spök-Dür, 2021). The common explanation for the disinterest in California is that natural gas in the state is inexpensive and highly predominant: 87% of homes use natural gas for water heating, and largely for space heating and cooking as well (CEC, 2021). In theory, using solar thermal in combination with natural gas can reduce 70%–90% of a household's water heating natural gas use in many locales. But with solar water heating systems often costing $8000 or more, even this slashing of fuel use rarely creates a very compelling financial decision under usual cost-effectiveness models.

California ran an incentive programme (2010–2020) to encourage adoption of solar water heaters in the state. Toward the middle of this programme, the California state energy agency funded us to help figure out how well existing solar water heaters were working and determine reasonable next steps to increase the technology's presence if doing so seemed like a good step. The larger study (Moezzi et al., 2019) funded by the agency aimed to produce a broad sociotechnical analysis of solar

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water heating in California, particularly to integrate insights about users and their experience with information on technical performance, the supply chain and its prospects, and evolving policies and general circumstances. One component of this research was interviewing solar water heater users. These interviews are the subject of this chapter.

We begin with a summary of the research background for the study, followed by a concise history of solar water heating in California and analysis of the interviews. The conclusion considers the role of such interviews in US energy technology policy.

Research Background

There has been much published research on the technical aspects of solar water heating and on its prospective performance, but little on the experiences of solar water heating users. One exception is a study of Australian households who used solar water heaters (Gill et al., 2015): it found that these households often lacked basic understanding of how these systems worked and were ill-prepared to take particular advantage of the solar portion by timing hot water use to coincide well with when solar-heated water was most available. Giglio and Lamberts (2016) examined relationships between household behaviour and solar water heating system efficiency for low-income households in Brazil (Giglio & Lamberts, 2016), also finding low levels of understanding of the technical system and clear dependencies between system performance and user behaviour. Ornetzeder and Rohracher (2006) examined a user-led self-build solar water heater movement in Austria, tracing how these users improved the technology in turn leading to a strong commercial solar water heating market in the country. A few others have focused on the diffusion of solar water heaters, such as on socio-demographic profiles of solar water heater adopters (e.g. Sharma, 2021) and on the technology's social acceptability. The latter concept is borrowed from psychology (for a conceptual framework, see Huijts et al., 2012) adapted to renewable energy technologies by Wüstenhagen et al. (2007). Haque et al. (2021) add sociological factors, such as social capital, perceptions of normality, and types of governance, to explain the social acceptance of innovative technology (namely,

solar water heating) by low-income urban dwellers in Mumbai and Cape Town.

In American policy-focused energy research, strong rationalistic representations of energy users are ported in from a long-standing dominance of engineering and economic paradigms, and a rooting of policy in a utility-regulatory context (Lutzenhiser, 2014). These dominated energy efficiency research for decades. With the shift on energy technology policy to a focus on climate change rather than efficiency itself, there has been some easing of this view, leaving more research space to examine how people use and experience technologies, and how this translates *in reality*, versus models and idealized expectations, to policy goals and societal effects. The potential value of better relating consumption research to effective policy recommendations has long been underlined, including by the authors of this chapter (e.g., Wilk & Wilhite, 1985; Lutzenhiser, 1993, 2014; Wilhite & Lutzenhiser, 1999, 2010, 2020; Shove, 2003, 2010; Moezzi & Bartiaux, 2007; Wilhite, 2008, 2016; Strengers, 2011; Bartiaux et al., 2016; Moezzi et al., 2017; Moezzi & Lutzenhiser, 2020).

To accomplish this, we need improved methods of multidisciplinary energy research, better coordination with what policymaking and research funders take away from research they fund or otherwise encounter, and recognition that applied research differs from, but is not inferior to, normal academic theorizing on consumption. There is still much left to do. In the US context, ethnographic interviewing of technology users about their uses, experiences, understandings, and conversations to inform policymaking is still rare; Wilk and Wilhite (1985) is one of the few examples. And what users say to neighbours, kin, and other acquaintances about the technologies they use is a major process for horizontal social diffusion of an innovation (Lazarsfeld et al., 1944; Katz & Lazarsfeld, 2006 [1955]; Rogers, 1995), but can also be often overlooked in policy studies framed as an issue of "individual adoption".

In Europe and Australia, social practice theories (Schatzki, 1996; Reckwitz, 2002; Warde, 2005) inspired many empirical studies on energy consumption.[2] These theories put practices on the front stage and consider them the unit of analysis. Academic research then extended to practices using water or energy (Shove, 2003) instead of focusing on perceptions or adoption of new technology. Topics studied include

heating practices (e.g. Gram-Hanssen, 2011; Sahakian et al., 2020), cooling practices (Hitchings & Lee, 2008; Wilhite, 2009), standby consumption in households (Gram-Hanssen, 2010), energy retrofits of homes (e.g. Bartiaux et al., 2014), laundry practices (e.g. Hess et al., 2018), and even practices of rescheduling appliance use in the process of PV panels appropriation (Winther et al., 2018).

Solar Water Heating in California's Past

Histories, though rarely invoked in applied research on energy technologies, can be a valuable source for "identifying often-overlooked considerations among practitioners who propose and implement energy policies" (Hirsh & Jones, 2014). We briefly cover the history of solar water heating in California. This history suggests that extending the reach of solar water heating systems is likely to be met with stiff competition. Solar hot water installations spiked in California in three periods: (1) early twentieth century; (2) 1970s and 1980s, and (3) 2010–2020.

The first solar water heaters in California were marketed at the turn of the twentieth century, simultaneously with early household electrification (Butti & Perlin, 1980). These simple systems competed with existing labour-intensive, dirty, and expensive methods of water heating using wood, coal, or manufactured gas. At the time, nobody expected abundant hot water in the home. Thus, the technology offered a substantial modernization toward higher levels of comfort, convenience, and cleanliness in the home.

These early systems encountered troubles. A rare freeze in Pasadena, a cradle of solar water heating at the time, destroyed many systems, bringing doubts about the viability of technology and stress for the new industry. The incident also underscored the lesson that, even in temperate California, solar water heaters risk early failure if not designed or operated to reduce freeze damage. The industry innovated and somewhat recovered. Meanwhile, the energy landscape continued to transform. By 1921, 87% of California homes had electricity. But it may have been commercial interests in creating customers for the vast natural gas resources in the state and elsewhere in the western US that most dimmed

the prospects of solar water heating. By the early 1940s, the market for solar thermal water heaters in California had nearly disappeared (Butti & Perlin, 1980). Research on solar thermal technology continued intermittently. While some countries, notably Israel (Berenbaum & Datta, 2020), eventually achieved widespread use of solar water heaters, there was little apparent interest in doing so in the US for decades hence.

The 1970s energy crisis brought renewed attention to developing American energy independence, and this merged with a growing environmental movement. Solar communities were built. President Carter installed solar water heating panels on the White House roof in 1979, predicting that solar water heaters would be commonplace by the year 2000. Governments provided incentives for solar water heaters and consumer informational pamphlets, including advice for "do-it-yourself" (DIY) systems. Seizing the opportunity, many companies jumped into the business of installing solar water heaters. The boom lasted only a few years. As Reagan took office, energy policy turned away from solar, removing federal incentives in 1982 and decommissioning the White House systems. The country appeared to re-embrace fossil fuels.

This 1980s experience left California familiar with solar water heating. Some companies from the 1980s were still in the solar water heating business during our study, and some systems installed in the 1980s were still in use, even fondly regarded by their owners. But according to industry experts we interviewed as part of the larger research project, the predominant legacy of the 1980s solar experience was negative. Our informants spoke of inexperienced, short-lived, and sometimes intentionally dishonest companies that had installed systems that never worked well, damaged the home, or failed quickly. Even for systems that had worked well, with the market decimated virtually overnight, it became very difficult to find affordable expertise or parts for repair to maintain.

From 2010 until 2021, the California Solar Initiative Thermal (CSI-T) programme provided incentives to encourage households to install solar water heating. A major goal of this programme was tapping the tremendous technical potential for reducing natural gas use by substituting solar thermal energy and supporting the market for future success. The programme was carefully designed to help guard against repeating the problems seen in the 1980s programmes. And incentivized systems

had to include a backup fuel. In contrast to the 1980s incarnation, there was little attention to DIY or simple systems even while some solar water heater proponents advocated this approach (Weingarten, 2016). The CSI-T Program covered a variety of solar thermal end uses, though our study concerns only single-family solar thermal water heaters with natural gas backup. Uptake was fairly slow, but sped up especially when the incentive amounts were boosted for low-income households. Under CSI-T, 8347 single-family natural gas backup systems were installed. This was much faster than the previous pace of solar water heating installation, but much fewer than originally envisioned or hoped for in the program.

Insights from Interviews

This section summarizes results from the interviews. Because people often communicate their everyday experiences in stories and examples, we include excerpts to share the logics and details these narratives communicate. To find solar water heater users to talk with, we used public satellite images, building permit data, professional peer networks, contacts provided by a solar water heating company, and recruitment from two 1980s solar communities. Fifteen interviews were completed, all in 2018, nine of which were at the interviewee's home. On-site interviews lasted 60 to 90 minutes, usually with one interviewee but sometimes with a couple. Most interviewees were in their 50s or older, and many remembered solar water heating from the 1980s.

Buying

Interviewees we spoke to had acquired their systems in a variety of ways: some bought a system under the CSI-T incentive programme, while others had bought theirs earlier, two even in the 1980s. Some who purchased incentivized systems paid over $4000 net, while others qualified as low income and had paid little or nothing.

Almost all the non-low-income households interviewed said they were motivated to install solar water heating by environmental concerns,

especially aversion to fossil fuel extraction and use. One interviewee was strongly against fracking:

> I want to minimize my use of natural gas because I abhor fracking … which I think is very bad to the environment; it's desecration of the land.

Fracking is rare in California; the distaste expressed here seemed more an ethical rejection of the gas industry rather than an expectation of direct effects.

Many reported having completed other energy-saving home projects. Those who paid for their systems often described careful reasoning behind their decision. Households that had paid thousands of dollars for their systems knew that as a financial investment, installing solar water heating pays back slowly in terms of saved fuel costs—20 to 30 years even under ideal assumptions—but they were willing to overlook this for environmental benefits. Nobody wanted to represent their purchase as financially stupid, but it seemed satisfactory to expect it to pay back over the system lifetime. These households were willing to lay out capital now to reduce future monthly costs, including the near-zero natural gas bills during parts of the year and the satisfaction this achievement brought. Others accepted the solar water system because it was essentially free, or because it was a bargain even though the net cost was more than a conventional replacement.

Many of the non-low-income households had already installed rooftop photovoltaic (PV) systems and were looking to get closer to all-solar energy for their home. But others explained that PV did not make sense for their situation. One man said that as his family lived in a mild climate and did not use air conditioning, their electricity costs were too low to motivate or justify PV. They also did not heat their home much, so increasing the efficiency of their natural gas furnace would scarcely save energy. Instead, solar water heating seemed the best way to reduce fossil fuel use and at less than half the price of PV.

Some said they preferred to green their electricity use by taking the low-carbon option from their utility and focus their direct technology investments on reducing natural gas use. Several voiced distrust of the PV industry and annoyance at common sales tactics for what was described

as relentless calls, exaggerated claims, and a lack of interest and expertise in customizing systems.

A few mentioned that solar water heating first appealed to them as a way to take advantage of the sunlight that fell on their property. For example, a Central Valley interviewee said: "It's hotter than blazes here. There's so much sunlight. We gotta do something". In rural Sweden, an owner of a micro wind turbine has the same willingness to use the resources of his surroundings: "Since I have my own land with extensive access to wind and sun, then, to me, it seems sensible to produce my own electricity. It's sort of like catching your own fish or growing your own potatoes. I find that awesome! It would make me more self-sufficient" (Tengvard & Palm, 2009: 1710).

The rural households we interviewed expressed interest in self-sufficiency and independence from grid-delivered energy. One mentioned that if their power went out, it could be out for a few days, versus the historically quick restoration expected in urbanized areas. In fact, most solar water heating systems in California depend on the centralized electricity grid to pump water. Still, in providing hot water that is relatively independent of natural gas and electricity, and often an extra reservoir of water as well, solar water heating systems fit into a self-sufficiency mindset.

Saving

Interviewers talked to households about how much they thought they were saving with their solar water heater. Many indicated that even if they wanted to estimate actual financial savings, it would take effort to do. For PV, utilities usually provide quantitative information on solar generation and how it translates to savings. There is no such provision for solar water heating. Household estimates of how much fuel or money they saved with their solar water heater were usually impressionistic, though some had done actual calculations based on utility bills—by comparing summer natural gas bills with solar water heating to those before they installed the system. Perhaps more than savings per se, low bills were a compelling reward. Households spoke with pleasure about monthly natural gas bills

of a few dollars during the summer, paying only the connection fee and perhaps minor costs for cooking and clothes drying. One interviewee who also had PV said:

> I like not getting an energy bill. You know that when you're saving 30 dollars a month on average the math just doesn't work, because you have to live in the house so many years to recover the repair costs.

One rural household said they installed the solar hot water system specifically to save on their water heating bills, which they said were high due to a small business on the property. Others mentioned that it would reduce worry in using hot water as liberally as they wanted. Most interviewees did not think they had high natural gas bills prior to installing their solar water heating system, whether because of conservative practices, small households, or the low cost of natural gas.

> I did do a fair amount of research on that and how much we would have. But frankly natural gas is dirt cheap. I don't think this system would even pay for itself. Our natural gas bill in the summer was like $10 to $15 a month for in the summer, for stove and hot water, and maybe $20 a month in the winter…We had to move our water heater, so we thought, for a few thousand dollars extra we can get water from the sun, so I guess it was more about the principal than the economics. …It was a bad investment…not because I'm disappointed with the system at all, but having a natural gas water heater is better…from an economics point of view.

The explanations and stories from interviewees show the varied pathways, thought processes, and actions that we would expect from humans.

Learning About the System

Many of the non-low-income households interviewed had someone in the household with either a technical education, technical job or hands-on experience, and knowledge about home projects and maintenance—including a real estate agent, a water industry engineer, and someone who had done a study unit on solar water heaters in high school decades

earlier. Those who had used highly experienced installers were satisfied with the explanations of how things worked. Good conversations with technology-savvy company staff during the decision and installation process may be quite influential in shaping how households use and understand their systems (Gill et al., 2015).

Only two of those who had questions about how the system worked said that they had attempted to read the technical manual provided with the system; most said they hadn't looked at it. User interfaces for the solar water heaters were not necessarily self-evident:

> This panel thing with LEDs… I've never really looked at that or taken the time to understand what's going on there. And there is a like a big fat booklet of how to understand these things, but I've never touched it.

One who did consult a manual had inherited a 1980s system in a planned solar community where they were common. She got the manual from her neighbour:

> The manual was useful because the control box was very confusing. You know there was a whole control system and then there was the pump and the tank, and when I first moved in it was just weird because the pipes were all on the side of the house and it sounded like a waterfall going through the wall. … I mean we were talking 1982 so it wasn't real sophisticated. So yeah I felt better having the manual.

It is even possible to have a solar water heating system and not know if the solar portion is working well or at all, since the backup natural gas system would still deliver hot water. One interviewee said that even the maintenance person she called in couldn't tell. Some households may hardly ever look at their bills, especially if they are on autopayment. Those who do look may be hard-pressed to explain cost variation from month to month. In fact, even a well-executed sensor-based performance measurement study might not give satisfactory answers (Moezzi et al., 2019).

A few interviewed households understood their systems quite well. But for many households, understanding the system and adjusting to it is not

intuitive or easy, as has been seen in other studies. For example, Australian households who tried to adjust their usage toward optimizing the efficiency of the system were the least satisfied with their solar water heating systems (Gill et al., 2015). The authors attribute this to lack of knowledge in how to adjust their usage, lack of clear feedback to facilitate these adjustments, and the strain and costs of having to adjust usage patterns.

Finding Installers and Repair Services

Solar water heating installers are concentrated geographically; some of the households we spoke to said it was difficult to find contractors reasonably nearby who could give competing bids for installing a system. Several also said that installers did not return phone calls or the contractor never showed up for an appointment. Even during the 10-year course of the incentive program, many contractors left the solar water heating business.

There seemed to be a notable difference in maintenance and repair issues between older and newer systems. The older systems included bigger tanks on the roof, which causes stress on the roof and potentially serious damage if there were a leak. Households with older systems said it was difficult to find contractors who were willing to help. Some of these older systems also required a fair amount of maintenance, such as draining and refilling the system once a year, or monitoring to avoid freezing problems. After enduring one or more failures, we heard, people gave up. One interviewee said:

> I wish all homes were built with solar and then there would be businesses in every community that would service those things, just like there's people that repair furnaces and stuff. … There's no reason why the furnace people couldn't be trained to repair solar.

While most people let the installer decide what type of system (of the many available options) to install, some did the research and knew what they wanted:

> I love the system and I did get my passive system. You can go for the smart systems but … they're more complicated and they're less reliable. I just love the simplicity of this system. There's nothing to break.

The latter quote points to an important dynamic in prospects for expanded solar water heating: the efforts to make "smarter" appliances with more advanced technology seem to promise more efficient operation and a better user experience. But—at least until these advances are perfected—this gives more opportunity for failure and requires skilled professionals to repair, sometimes on repeat, in turn increasing hassle and costs. The complexity distances the technology from the user, whereas the most positive experiences with solar water heating may come from households that have the capacity and interest in interacting with them (see, e.g., Ornetzeder & Rohracher, 2006).

The CSI-T programme specified detailed requirements for systems to qualify for the incentive. Working within these parameters, one installer designed a general configuration of a tankless (on-demand) backup system with two collector options that exactly met the incentive level for the low-income programme ($4388, half the cost of the systems predominantly installed early in the programme), leaving no financial costs to the system owner. The contractor, a late entrant to the solar water heating industry, installed 52% of all the single-family water heating systems in the programme, predominately in one of these two configurations, clustered in a few zip codes, and in the last few years of the 11-year program. The second-most prolific installer accounted for only 7% of programme installations. Incentives thus were presumably very influential in bringing in this new entrant, and in turn to what technical configurations were installed. How these systems perform may have major implications for solar water heating's reputation, but this performance has not yet been studied.

Beyond energy savings and environmental interests, some interviewees said that they were partly motivated to install a solar water heater in order to create more space in their home, such as moving the hot water tank from their kitchen to the roof. Some older solar water heating systems had huge tanks with a reputation of being clunky and ugly:

> [The older systems] took up, if you took a car and you put it on its end. So it was vertical instead of horizontal then the tank was about the size of a compact car. They were huge. And so when those things would leak the water would go all over your garage. The drywall would get wet so they'd have to replace the drywall.

Talking with Others

Rooftop PV installation has been shown to have a contagion effect, with visibility among neighbours and peers encouraging higher rates of installation (Irwin, 2021). For example, around 2010, in Belgium, PV panels "appear to be an asset for displaying higher economic and symbolic capital" whereas at the same time, in Portugal, they "are seen as smart gadgets and as a source of prestige only among small groups of well-informed people". (Bartiaux et al., 2016: 417, 420). Solar water heating seems to generate less discussion. Most of those we talked to did not seem interested in demonstrating their environmental credentials or technological adventurism to neighbours and were content with having their system out of sight—sometimes preferring it that way, given that solar water heating systems seem to have had a widespread reputation (rooted in history) of being ugly and clunky, as noted above; some mentioned that the looks of the system and its effects on the home's curb appeal had been a matter of family debates.

While some interviewees said that their neighbours were interested in their solar water heating system when it was first installed, that interest tailed off and the system sparked no further discussion or interest. In California's energy transition planning, rooftop PV looms large as a key element of smart grid where household "prosumers" generate and sometimes store electricity for the grid. Solar thermal water heating has no such role. One interviewee described how he did try to talk up his solar water heater but failed to get traction:

> I tend to try … evangelize a bit on all this stuff, but I find that my neighbours are fairly old in general, and they seem to have very little interest in this at all. Either they don't understand solar or they are put off by the pitches from various local solar companies mainly putting in PV systems in.

If hot water is ever a topic of conversation, one interviewee noted, environmentally concerned people he talked to asked about on-demand water heating, not solar energy.

Water Practices

We analysed two types of interrelated practices among solar water heating owners: monitoring practices, and daily hot water use. Monitoring the solar contribution to the hot water consumed is difficult because of the coordination between the water inflow from the solar hot water system and the gas backup system. Should the solar not produce, the backup kicks in, and which energy source is being used is invisible to users. However, some households said they experienced hot water surges on hot days, or lower hot water temperatures in the winter or on cloudy days. One interviewee said that they have a metre on the solar storage tank that they read every week, and a switch to turn the backup tank heating off if they believe there is ample sun. This monitoring practice is made possible by these devices and by expertise and engagement of the owners.

Even for PV, research that compares practices before and after solar installations are rare. For PV, Palm et al. (2018) note that the results of these few studies are mixed. In their own research with PV prosumers in Sweden, they found big variations across households but no general behavioural change, with households explaining that they thought the benefits of shifting their electricity load were minimal.

Most of the California households we interviewed did not immediately report changing their hot water practices much after installing or moving into a house with solar hot water. With the interviewer's empathic listening, however, answers were sometimes qualified:

> Interviewer: Have you, would you say that it's changed having that solar thermal hot water, has it changed the way you use hot water in the house?
>
> Interviewee: No, I wouldn't say… No, I just treat it as it is effectively reducing the gas bill when it's working. So, I can have as long a shower as I like.

In one case, to keep the roof panels from overheating, a household increased its hot water use by washing white laundry at high temperature. Others took advantage of the "free" hot water, including the fact that there was more of it due to the storage added when converting to solar hot water (e.g., increasing from 30 to 90 gallons, in one household's case).

> In the summer, you have plentiful hot water, and you use more of it. So there's a benefit that doesn't even show up in the break-even analysis that we weren't aware of… We didn't realize that we would have so much hot water in the summer and that you would actually change the way you behave.

So the virtually endless hot water, heated for free, could be a big if unexpected perk. The free heating also eased worries about the cost of using as much hot water as one wanted:

> Now I'm not afraid to use hot water. Especially because my mother is 97 and I have to wash the sheets and everything often. … Now I just use hot water and everything is fine.

In these cases, solar water heaters have "the potential to script behaviour" and to change daily practices, as shown for air conditioning in the U.S. South (Wilhite, 2008: 128). The changed behaviours in response to a sense of cost-free hot water made possible are interesting in terms of water use as well, especially since California increasingly finds itself under drought conditions.[3]

Solar water heater users have been classified as "passive" or "active" (Gill et al., 2015). Some of the most technically oriented owners were active users, often timing their use of hot water to correspond to times when there was a high solar portion of hot water, even switching the auxiliary tank off when they knew it was not needed:

> Our goal was to use the hot water in the evenings like shower in the evening because you can pretty much guarantee that there'd be hot water at that time. In the morning it was less sure. But as long as the backup is working there's generally hot water available.

The possibility of changing practices to complement the solar water heater is interesting for several reasons: it not only changes the efficiency of the water heating system, but also orients users toward coordinating with a natural rhythm—as also noted for PV panels in Norway by Winther et al. (2018)—contra the "anytime" invitation of modern fossil-fuel based energy. This touches on an important point about technological devices and users—technologies are not "used" in a singular way. Although always constrained by technical designs, "use" is also very much a process in which devices are made intelligible by users in terms of their capacities and understandings (Reckwitz, 2002), and by their needs, wants, and ethics as they see them (Hackett & Lutzenhiser, 1985). It is not surprising, then, that "conservation" may under some circumstances mean using more "free" hot water for new uses because it would otherwise be wasting it.

Overall Recommendations from Interviewees

We asked interviewees for what they would recommend to California policymakers in regard to supporting solar water heating. Virtually all who had installed a solar water heating system under the incentive programme emphasized the importance of programme incentives to their own purchase and said these would be necessary if policy aims to increase solar water heating adoption. Some mentioned their internet searches on solar water heating and gave summaries echoing those views, indicating how powerful well-written blogs and non-government information can be. Others regretted the difficulty in tracking the benefits of the solar hot water system, noting that there was no easy way to estimate how much of their hot water was heated by the sun. Another emphasized that relative to PV, there has been hardly little marketing or customer profiling of solar hot water users. Instead, the technology may retain its 1980s association with alternative energy aficionados and with a disappointingly short run. So there is need, the interviewee suggested, to rehabilitate solar water heating's reputation if it were to achieve wider acceptance in the present.

Despite the reservations outlined above and a nearly unanimous sense that at full cost, the systems were not very cost-effective, many interviewees took pleasure in their system and often its role in homemaking and in providing true environmental benefits:

> It makes you feel a little bit more environmentally friendly. (…) I think it's kind of cool to have solar power on my roof. (…) it just makes me feel a little bit more house proud (…). People want Solar, people want to feel better about themselves, especially in a way that's quite public. It's like, it's like "look at me." Like it adds benefits in that way. And I think people, especially in the [su]burbs want to have that.

Technical Conclusions

These interviews, in combination with other data gathered in the project, led us to conclude that there were favourable niches where solar water heaters may fit quite nicely, such as households in rural areas, those with high hot water needs, and those interested in solar beyond money savings. But it is hardly easy to target such niches.

Beyond the question of potential adoption levels, there is the question of whether California climate policy should bother with solar water heating: how much fossil fuel use do they displace? The answer depends on usage patterns, the technology, its installation, and how system performance evolves over time. Our provisional conclusion in the larger study, based on available data, is that solar water heaters in California usually work, but often less well and sometimes much less well than the ideals of 70%–90% displacement (Moezzi et al., 2019). Actual savings depend on multiple factors, including the actual quality of the installation and on hot water draw patterns, that is, on the distribution and volume of hot water use throughout the day, which is often quite different than those historically assumed in water heating efficiency models (Lutz et al., 2011; Maguire et al., 2013). In short, it is possible that solar water heaters in California could displace a great deal of natural gas use, but it is also possible that their performance is considerably lower than modelled ideals.

Versus the experience of technological improvements in Austria (Ornetzeder & Rohracher, 2006), the California industry has not visibly achieved a perfectly suited system. One can envision, however, revitalized engineering research to produce affordable, easily integrated solar water heating systems with a more modern aesthetic, resilient features, less need for customization, and easier to repair, all of which are different goals than perfecting theoretical efficiency. These could be designed in coordination with social science research on user practices and wishes, including for example, the aforementioned interest in measuring natural gas savings.

While these directions might have merit, in the meantime, the policy and technology landscape of California has pivoted in a way that again puts solar thermal water heating in disfavour. Municipalities continue to ban new natural gas hook-ups, and the state plans to eliminate most fossil fuel use, whether for direct use or to generate electricity, by 2045. Solar thermal water heating with natural gas backup, as studied here, does not fit with this view, especially with the 30-year expected lifetime of these systems. It perpetuates natural gas use, clashing with policy directions. In addition, the networked aspect of PV in an interactive grid, where electricity generated is at least potentially sold rather than wasted, is also far more aligned with the planned future energy system. For solar water heating, in contrast, the heating provided is wasted if not used by the household.

Research Conclusions

Academic research on energy consumption aims to improve theorizing about the dynamics of consumption. The goal of this project was not to contribute directly to that enterprise, but rather to bring the benefits of some of this theorizing closer to the problems of policy. To concretely achieve this, there were multiple challenges to overcome, including matching the outputs of consumption research to what policymaking is able to process.

The interview results sketched above spotlight households rather than technical devices in isolation. They induce a number of small stories that

can be woven into how the landscape of solar water heating and prospective development are seen. For example, we learned that rural households had different representations than more urban users of what solar water heating is about, how little curiosity solar water heating owners experienced from their neighbours, why solar thermal water heating is sometimes much more attractive than rooftop PV, how owners thought about energy savings, the appeal of endless hot water, and how the limited supply of skilled professionals impedes choosing solar water heating.

The results of these interviews are modest, in that they do not provide traditional "aha!" moments and are not easily responded to by crafting technological, policy, or marketing changes. But they do provide counterpoint to default assumptions about why people do what they do. By disrupting the concept of average households doing average things for average reasons, the interviews illustrate the variety of projects involving solar water heating systems, the diversity of opinions thereon, and the range of benefits these systems provide, including psychological and emotional ones. And while from a social science perspective these ideas are second nature, in the technology policy world, they are not. When technological solutionism predominates, people tend to be seen in caricature, as consumers whose main purpose is to buy the correct technology. The best value of alternative stories such as those told by interviewees may be their potential to contribute to changing the ways that climate policymaking sees people, where the patterns and relationships represented in the experiences they relate become useful pieces of the puzzle in forging a better energy system on the ground.

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Notes

1. Statistical data are from CEC (2021) as reported in the 2019 Residential Appliance Saturation Study Reporting Center (https://webtools.dnv.com/CA_RASS/).
2. While we applied practice theory in our research and the discussions below, we centre our vocabulary on technologies and users to retain a natural vocabulary as suited for reporting applied research.
3. Most households pay for water by volume, but the rates can be quite low.

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