Renewable Energy Retrofitting and Energy Poverty in Low-income Households

Research report for United Housing Cooperative

Dr Ellis Judson
Dr Farnaz Zirakbash
Dr Andi Nygaard
Dr Angela Spinney

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Executive Summary

This report summarises the findings and recommendations from a pilot study titled *Renewable Energy Retrofitting and Energy Poverty in Low-income Households*. This collaborative industry research project between Swinburne University and United Housing, a community housing provider, investigates the effectiveness of small scale photovoltaic (PV) installations and energy performance feedback in alleviating energy poverty for cooperative housing tenants. The study identifies the social and financial benefits associated with integration of PV technologies in eight low-income rental households in the western suburbs of Melbourne, with the aim of evaluating the potential to meet the needs of tenants in community housing.

This research was funded through a seed grant provided by Swinburne University Research Institutes, with support from United Housing.

Research aims

This pilot study aims to provide increased understanding of the benefits and costs, and challenges of retrofitting solar PV to cooperative housing tenants, and provide insight into the effectiveness of PV installations in reducing energy poverty through self-generation and managing energy consumption.

In seeking to understand the effectiveness of solar PV in engaging tenant households in community rental housing to manage their energy use and alleviating energy poverty, this study:

1. *investigates the benefits and challenges of electricity co-production and for low-income tenants in community rental housing*
2. *explores the potential of PV for reducing energy hardship in community rental housing*
3. *identifies key issues for community housing providers installing PV and how these may be managed*

Effectiveness is evaluated through: understanding whether photovoltaic (PV) installations and energy performance of dwellings reduces the risks of energy poverty and energy deprivation in low- income families; and assessment of the social and financial cost- benefit of PV installations in co- operative housing. The findings are intended to inform the potential for subsequent extension of PV installations for the co- operative housing organisation partner and scaling up in the sector more generally. In addition, the research findings will inform the development of effective mechanisms to alleviate energy hardship, and contribute to social and environmental goals. As such, the findings will be of interest to a range of stakeholders including community housing providers, the energy industry, consumer advocacy organisations, government policy makers and regulators.

Methodology and conceptual approach

As energy use associated with households is multifaceted, the research uses a mixed methods research design comprising a range of data and different data gathering techniques, and focuses on: a high-level review of the relevant literature relating to renewable energy retrofitting in social housing, qualitative interviews with eight member tenants, and analysis of household electricity consumption before and after installation of solar PV. As a preliminary to the project the housing provider engaged an independent contractor to conduct pre-installation home energy assessment providing baseline information about each dwelling's construction, energy efficiency and comfort.

Taking an interdisciplinary social science approach allows the research team to identify a range of behavioural and context-specific variables that influence integration of PV into participant households, and any changes in energy consumption. The interaction between new renewable energy technologies and user behaviours, and effects on energy poverty can be explored.

Key Findings

- *The pilot project successfully reduced the barriers for PV technology adoption for low-income rental tenants in cooperative housing. As member tenants the participants had access to physical roof space (this was complicated in one instance where roof space was shared). The financial barriers were reduced by the housing provider and Victorian government subsidising the installation of PV upfront. The energy efficiency assessment was also subsidised. The tenants were responsible for paying meter reconfiguration fees to the distributor. However, as households are responsible for organising the electricity retailer, and may not have the capacity to evaluate the many different offerings, or may be limited in their choice due to pre-existing debts, tenants may not be getting the best retail tariff to optimise financial benefits from solar PV.*

- *The more complexity in the household, the less likely control over electricity consumption or effort in reducing energy expenditure. The low-income and sole parent households in this study are facing increased emotional and financial pressures. Managing health conditions or complex family relationships may limit capacity to expend on thinking about or engaging with electricity consumption. Although participants are looking for ways to reduce energy expenditure, they are not highly motivated to pursue those matters e.g. switching energy providers, or changing routines, where they perceive that this will involve considerable investment of time and effort but not lead to material improvement.*

- *Initial analysis suggest that individuals engaging in production, as well as in monitoring and managing their electricity use to a greater extent, leads to more active ways of relating to energy. This finding concurs with previous research undertaken with owners of PV panels. However, given the limited size and duration of this study, this could not be fully tested, and further research is required to evaluate how low-income households are using the Solar Analytics app for aligning consumption with production and effectiveness of this approach over a longer period for reducing electricity bills.*

- *The main benefits identified by residents in interviews were reduction in electricity bills through use of self-generated solar electricity and credit for excess electricity exported to the grid, together with perceived increase in control over energy use. The calculated savings plus credit for export during the study period (17 October to 11 December) range from $117.21 (Dwelling 6) to $162.76 (Dwelling 4). This works out to be around $2.09–$2.91 per day (combined Direct and Indirect benefit) to off-set the grid supplied electricity costs. However, the financial benefit is likely to be higher/lower depending on the time of year, and negative during winter when demand exceeds generation.*

- *Where participants had reverse cycle heating/cooling in addition to gas heating, a further benefit was ability to manage energy consumption through switching energy source to electricity when actively generating e.g. using air conditioning during hot days, or improved comfort by using reverse cycle for heating one room rather than whole house gas central heating. Some participants reported lower electricity bills and feeling less stressed about energy bills.*

- *Other, indirect benefits identified through qualitative interviews include improved awareness of electricity consumption, and increased confidence in engaging with the energy market. Two participants reported switching energy retailer after the first interview with the researcher. However, others were not confident that switching retailer/tariff would be of benefit to them.*

- *One of the most significant potential financial benefits offered by PV is in providing an alternative to participation in hardship plans and in reducing energy-related debt. However, this may require the development of different business models, such as allowing transfer of credit for excess solar electricity to pay off arrears. It is dependent on the willingness of tenants to engage more with the energy market and change their current arrangements.*

- *Technology and increased literacy can offer pathways to co-managing electricity consumption. The findings suggest that there is potential for monitoring and visualising electricity as a means of assisting low-income households to better manage their generation and consumption, and reduce expenditure. All households had smart phones and other devices, and internet access. Most participants were open to ways of using technology to take control – however, confidence and skills for using digital technology varied. Given the particular socio-economic and cultural backgrounds, face-to-face coaching through trusted intermediaries and/or peer-to-peer learning is recommended to improve technical capability and energy literacy.*

- *Flexibility in routines and ability to adapt household activities is key to maximising financial benefits of self-generated electricity. Most participants indicated that they would be willing to shift some household activities e.g. laundry, dishwashing, and to some extent cooking, to when the PV is generating. However, the level/extent of capability and flexibility varied between the different households, as indicated by the load profiles. Households' electricity consumption profiles indicate that they are modifying their routines to take advantage of solar electricity during the daytime. The integration of easy control functions e.g. timers in new appliances such as washing machines and* *dishwashers, could assist households in aligning consumption with generation. The key motivation for low-income households in this study is reducing electricity bills and energy debt.*

- *An increase in electricity consumption was observed after installation of PV for households with Solar Analytics energy monitors. This indicates a 'PV rebound' effect*[1] *which is estimated to be between 16-54 per cent for monitored households, which is higher than found in other studies*[2]*. In simple terms the rebound effect is the reduction in the energy savings produced by an efficiency investment due to higher consumption, either in increased use or a higher quality of energy service by the consumer*[3]*. The amount of energy imported from the grid showed a slight increase over the study period following installation of PV for some households – with accompanying risk of increased costs. However, given the small size of the sample and limited timeframe for analysis, this needs to be tested further on a larger sample over a longer time period.*

- *The findings indicate that the PV industry is still not mature: in this study the PV installers did not satisfactorily complete installations in all households. At least three of the participants experienced installation issues: the procedure for meter reconfiguration did not progress due to lack of communication between the different agencies/industry stakeholders, which led to households not receiving the credit for solar feed-in. In one instance this had still not been resolved 10 months after installation. This study demonstrates that low-income rental households require support during installation and afterwards, to assist in interacting with the multiple agencies/industry stakeholders involved, particularly if there are technical problems. This has resource implications for the housing provider and may necessitate the involvement of other support agencies.*

- *Key obstacles for roll-out of solar PV to low-income tenant households in this study are low levels of energy literacy, lack of understanding of the system and initialisation procedures. Participants' previous experience contributed to a reluctance to engage with electricity retailers, particularly for those households whose first language is not English, as this takes up time and involves concerted effort for the participants who are all sole parent households. However, participants were comfortable interacting face-to-face with trusted intermediaries including their housing provider, and independent energy assessors that visited their homes, and showed interested in learning more about ways to reduce energy costs in their home.*

- *The quality of the housing stock and existing inefficient appliances reduces the benefit of solar PV for households. In particular, housing construction and design impacts on occupants' comfort in hot weather, with increased household electricity consumption for cooling. An audit of household appliances was not carried out as part of the home energy assessment. Appliances account for around 30 per cent of household electricity*

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[1] The Rebound effect or take back captures the idea that decreasing the marginal cost of energy by making it cheaper and/or more abundant through investment in energy efficiency may encourage increased usage of energy. For some households there may be a "solar rebound effect." As with energy efficiency, solar system installation may present occasion for a take-back effect as it may reduce the marginal cost of energy to the consumer.
[2] Maxwell et al 2011 estimated 10-30 per cent; Deng and Newton 2017 estimated PV rebound to be 17-34 percent depending on the Feed in Tariff.
[3] Herring and Roy 2007: 195.

use. Some households had older inefficient or defective appliances e.g. fridges, portable air conditioner which can lead to increased electricity consumption.

Recommendations

1. *PV is well-suited to social housing where there is high daytime occupancy rates. However, benefits are limited if tenants do not understand or adapt their electricity use to maximise savings. To maximize on-site use of solar housing providers need to provide effective guidance to tenants and support them to make behaviour changes.*

2. *Home energy assessment should include an evaluation of householder capability for PV, and audit of appliance efficiency. There is an intermediary role for trusted housing support agencies, third sector organisations and industry contractors to assist households with their PV utilisation and to provide tutorials to improve energy literacy and assistance with home economics including how to plan daily/weekly activities to take advantage of the solar resource.*

3. *There is a need for alternative strategies for reducing energy bills and new models to reduce energy-related debt for households using solar credit. This may include eligible households signing up to participate in demand reduction trials with energy retailers e.g. Energy Australia, where households receive payment just to enrol, plus financial reward each time they are asked to respond to a peak demand event by reducing electricity use, and a bonus payment if the participant makes significant shifts to electricity use outside the critical period. Other opportunities could include participation in virtual networks to trade solar electricity generated, through the cooperative or other mutual interest organisation.*

4. *Opportunity to increase social learning from this study to assist in peer-to-peer learning for other households and cooperative housing organisations integrate and use solar PV. This approach is consistent with the cooperative ethos of education and training to contribute to the development of the cooperative, and cooperation to meet social and community needs.*

5. *Further explore opportunities for community housing providers to engage with new models for purchasing electricity (e.g. Powershop - a subsidiary of Meridian Energy) – to enable vulnerable energy consumers to access electricity when it is more affordable.*

6. *Further explore the potential for the community housing sector to participate in schemes that incentivise demand response i.e. to reduce demand at peak events (see for example, Amber Energy in South Australia). Households with solar can decide to participate in calls to reduce usage, for financial benefit.*

7. *The benefits of installing electricity monitors to visualise solar electricity generation and consumption to a household's smart phones has yet to be fully evaluated over a longer period. Monitoring electricity in real time has multiple benefits, including:*

communication to the householder when the PV is generating (and when to run appliances); keeping track of usage and providing information about the cost; real-time and historic data can assist in understanding patterns of electricity consumption and identify the most appropriate tariff for the household; the Solar Analytics monitors in this study assisted in fault diagnoses for one of the PV systems which was underperforming due to voltage exceeding the safety limit.

Table of Contents

Centre for Urban Transitions
Swinburne University

Renewable Energy Retrofitting and Energy Poverty in Low-income Households

1. Introduction

This research explores the social and financial benefits associated with integration of PV technologies in eight low-income rental households in the western suburbs of Melbourne, with the aim of evaluating the effectiveness of rooftop PV to meet the needs of tenants in community housing.

The pilot study seeks to provide insight into the effectiveness of PV installations in reducing energy poverty through self-generation and managing energy consumption. As energy use associated with households is multifaceted, a range of data and different data gathering techniques are used.

Why study low-income rental households and solar PV?

Energy affordability has become a major public and policy issue after a sustained period of electricity and gas price increases across Australia, with low-income households living in rental accommodation amongst those most at risk from rising energy prices[4] [5].

> People living on low incomes are experiencing significant pressures as a result of substantial increases in the cost of electricity, without a concomitant increase in income. Low-income people are most likely to live in poorly-insulated and inefficient rental accommodation, and spend a higher proportion of their income on energy, water and energy than others. They are least able to respond to increases in prices and to invest in more efficient homes. Given that energy is an essential service, energy price rises leave the most vulnerable households with little option but to pay the extra.[6]

The term 'energy poverty' is used to describe different types of energy-related stress and has a number of dimensions: households' inability to pay energy bills, but also restricting energy spending to the detriment of health and wellbeing, and having relatively low income and spending a relatively high proportion of income on energy. [7] Indicators of energy-related stress, such as electricity or gas disconnections and

[4] ACOSS (2013).
[5] Chester, L., Elliot, A. & Crossley, P. (2018 :29-32).
[6] Commonwealth of Australia (2012) Senate Inquiry into Reducing Energy Bills and Improving Efficiency, Canberra, Commonwealth of Australia.
Australian Council of Social Service (ACOSS), *Submission 67*, p. 4.
[7] Azpitarte, F., V Johnson V., & Sullivan, D. (2015).
Chester and Morris (2012) identify "a real and growing problem for Australia's 3.5 million poorest households" and define energy poverty in the context of low-income households living with rapidly escalating energy prices.

participation in energy hardship programs have risen in most Australian jurisdictions. In Victoria, the geographical focus of this study, demand for Utility Relief Grants for paying electricity bills more than doubled from nearly 11,955 in 2009-10 to 29,942 in 2017[8] [5].

Evidence suggests that energy hardship is increasing. While disconnections for non-payment declined in 2015-16, rates steadily increased in 2017 (particularly for electricity), with 46,083 residential electricity and gas disconnections in 2017[9] [10]. The number of customers participating in hardship programs continues to grow and the level of debt is high. Some 80,000 customers participated in hardship programs during 2017, and the average debt to retailer of customers on those on programs was $1,564. In the first quarter of 2014–15, there were just over 23,000 customers in retailer's hardship programs but in December 2017, that number had grown to 37,935[11]. There is concern that hardship programs are becoming increasingly ineffective. Other, more effectual measures are required, that minimise vulnerability to rising energy prices and associated debt.

Why is energy affordability important?

Energy affordability affects many different people, but those living on low and fixed incomes and families with children are particularly vulnerable[12]. Reasons for higher household expenditure on energy use include poor energy efficient housing, running older, inefficient appliances, poor energy literacy, spending more time at home, sub-optimal energy retail contracts, households on low incomes, or needs associated with health or disabilities.

Energy-related financial hardship is often hidden, as some people prioritise the payment of utility bills above other household expenditure and may constrain their energy use, sometimes to the detriment of their home comfort and health[13]. Inability to keep the home adequately warm (or cool) can have wide ranging social impacts, including on mental health (e.g. stress, social isolation), physical health (e.g.

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[8] DHHS (2010)
[9] ESC (2017:59).
[10] AMES Australia,*Submission to ACCC Issues Paper*, June 2017,p.2. PIAC found in a survey on disconnection that disconnection was about more than the bill but about several demographic factors working together. Such factors include, but are not limited to, having a medical condition, mental illness, intellectual disability, being a new migrant, unemployment, and speaking a language other than English. Their findings supported 'the conclusion that people who get disconnected have often faced multiple sources of disadvantage' (ACCC 2018).
[11] ESC (2017) Media release: *Energy stress still high despite fall in disconnections,* 29 March 2017; Victorian Energy Market Update, April to June 2018.
[12] Chester, L.(2013).
[13] Green, G., & Gilbertson, J. (2008).

malnutrition, increasing morbidity and excessive mortality through inadequate heating or cooling), and limit future opportunities (e.g. impacts on schooling)[14 15].

Energy hardship and deprivation has a significant negative impact on low-income households, with implications for registered housing providers[9 16].

Improving the energy efficiency of dwellings can reduce reliance on mechanical heating and cooling, and improve financial and health outcomes[17 18]. Commonwealth and state and territory governments' have introduced a range of energy efficiency programs and concessions. However, challenges for improving energy efficiency in low-income rental households, include: lack of access to capital for purchase, split incentives and conflicting or complex information[19]. There remains a need for more impactful energy savings initiatives to make energy more affordable for consumers[20], and improve consumers' ability to participate in the electricity market[21].

Could solar PV be a remedy for reducing energy poverty?

Many Australian households have reduced their energy consumption by investing in energy efficient appliances, home upgrades, and installing rooftop solar panels in response to sharp rises in energy prices.[22] Solar customers are paying, on average, $538 per year less than non-solar customers, suggesting that affordability concerns are most acute for those customers who have not (and possibly cannot) install solar PV.[23]

Low-income households have much less capacity to influence housing energy efficiency to reduce their energy demand and stem the growth of energy bills as prices rapidly rise.
Previous research found that low-income households have reduced their energy use in response to rising energy bills, but the scope for further reductions is significantly limited[24]. People on low incomes are unable to invest in high value energy efficiency

[14] Studies have begun to document impacts on *mental* health, most notably borderline depression and general anxiety. Here, the consensus of findings is even more convincing than it is for effects of physical health. Living in cold and damp housing contributes to a variety of different mental health stressors. See for example: Nicholls, L. & Strengers, Y. (2017) *Rising Household Energy and Water Bills: Case Studies of Health, Wellbeing and Financial Impacts,* Victorian Council of Social Service, Melbourne.
[15] Studies in New Zealand and the UK have linked cold-related mortality with low incomes and hard-to-heat buildings. Also, research by Gasparrini, *et al.* 2015 Mortality risk attributable to high and low ambient temperature: a multicountry observational study**,** Lancet, 386 (2015), pp. 369-375 identifies premature deaths through heat and cold.
[16] CHFV (2017).

[17] Moore, T., Strengers, Y., & Maller, C.(2016).
[18] Russell-Bennet et al (2018).
[19] ACOSS (2013); Cornwall et al (2016); Chester (2013).
[20] Commonwealth of Australia (2012) Senate Inquiry into Reducing Energy Bills and Improving Efficiency, Canberra, Commonwealth of Australia.
[21] Chester, L., Elliot, A. & Crossley, P. (2018).
[22] AEMO (2012).
[23] ACCC (2018).
[24] See Chester L. (2013) *The impacts and consequences for low income Australian households of rising energy prices.* University of Sydney: Sydney. This report highlights the significant qualitative impacts of energy costs on lower income households. Other Australian research on the depriving impacts of energy costs is most commonly produced by charitable and other non-profit organisations such as the Australian Council of Social Services), the Brotherhood of St Laurence, and St Vincent de Paul Society.

upgrades such as energy efficient appliances, solar hot water systems or solar PV systems as a way of reducing operating costs, due to lack of access to capital. Renting also has particular impacts on households' experiences of energy deprivation – compromising social, physical and mental health and wellbeing[25], and landlord's agreement is required for improvements to rental properties [26]. These barriers are evident in: the lower incidence of insulation in low income housing and tenanted properties, higher rates of ownership of inefficient appliances that are cheaper to buy but expensive to run, and low take up of rooftop solar systems in rental housing. Given potential equity implications of Australian residential PV policy further research involving low-income tenants is warranted.

Currently, there are few examples of programs targeting solar PV in low-income rental housing. Research to assess the impacts of solar PV in low-income rental households in Australia is limited[27]. By taking a user perspective, this report seeks to understand the challenges and benefits of PV for managing electricity consumption and reducing energy poverty amongst low-income tenants in community rental housing in Melbourne, Victoria, and effectiveness in addressing energy affordability.

2. Research design and methodology

2.1. Recruitment and engagement

The Centre for Urban Transitions was engaged to undertake this pilot research on behalf of United Housing Cooperative in order to understand the benefits of PV for their member tenants, and the community housing sector at large. For this pilot study, households were recruited through the rental housing cooperative: United Housing provided contact details for member-tenants who had expressed an interest in having solar installed and who indicated that they would be willing to participate in the research. Following assessment of the dwelling as suitable for rooftop PV and the system scheduled for installation, a member of the research team contacted each potential participant to confirm their eligibility, provide information about the research and to obtain their consent. The researcher then organised a time and venue for the first interview.

Eight households were included in the study. From the initial cohort of member tenants who consented to participate, one participant withdrew, and another left the study after the first interview, due to relocation out of the area. The incoming tenant agreed to take part in the study. However, due to change in electricity account holder, the household electricity consumption data could only be obtained for this participant from the date of commencement of occupation (from August 2018).

[25] Liu, E. & B. Judd (2016)
[26] Liu, E., Judd, B., & Santamouris, M. (2017).
[27] See review by McCabe, A., Pojani, D. & van Groenou, A.B. (2018).
See also: Chester, L., Elliot, A. & Crossley, P. (2018)

United Housing Co-operative aims to provide appropriate, affordable and secure accommodation for low to moderate income families in housing need. Participants are sole parent families with children living in cooperative community housing in Melbourne's western suburbs. Seven of the eight households are from a range of migrant backgrounds, having lived in Australia for between 7-21 years. All participants are female-headed, sole parent households.

The number of persons in each household ranged from 4 to 9 persons. Participant households include sole parents with 2-8 children, and included an extended family (three generations living in the same house). All interview participants are women, aged from 20-24 to 45-54 years. Six households are within the two lowest household income quintiles, and one is within the third household income quintile (ABS 2017), with the median household income being $600-$799 per week. The main source of income for all participant households is Government Allowances. Most had low levels of educational attainment and limited English literacy. Some dwellings have occupants with identified special needs: these include physical health conditions, mental illness, and relationship breakdown due to domestic violence. In the first round of interviews (May/June 2018) none of the tenants interviewed were in paid employment, although three were undertaking part-time study and one also volunteering. During the second round of interviews (October/ November 2018) two participants were in part-time casual employment. A summary of participant demographics is provided at Appendix A (Table A1).

The PV system was installed at no upfront cost to households: United Housing contributed 25 percent to the cost of installing PV, and the balance provided through the Victorian government. Installation was coordinated by the housing provider, and tenants' contribution was limited to the meter reconfiguration fee. Physical (roof space) constraints and regulatory issues led to delays in installation of PV systems on two properties, which extended beyond project timelines. Electricity consumption data could not be accessed from three households, which are located within the Jemena electricity distribution network. As a consequence, researchers were unable to proceed with quantitative analysis of electricity consumption for these households..

Solar Analytics monitors and 12 months data subscription were provided by Swinburne University in four households at no charge. Participants that completed the research were given a $50 Coles/Myer voucher.

2.2. Data collection and analysis

For this mixed methods study[28] [29] monitored electricity production and consumption is combined with qualitative methods of data collection to provide the data necessary for exploring behavioural and social or cultural aspects of domestic energy consumption. Interviews were conducted with tenants to map their energy service needs, behaviours,

[28] Ambrose, M., & James M (2017
[29] Moore, T., Strengers, Y., & Maller, C.(2016).

their understandings and expectations of solar PV. Electricity consumption data is used to identifying patterns or changes in electricity before and after installation of the PV system. In addition, temperature and humidity data was collected to monitor thermal comfort.

The study draws on pre-installation energy audits to evaluate energy efficiency of the construction, existing heating and cooling systems, and an overall rating for the performance of dwellings.

2.3. Interviews

Face to face interviews were conducted with member tenants to map occupants' needs, understanding and expectations. All interviews were conducted in English except for one, where a translator was present. English is the first language for six of the eight participants. Although seven participants responded to questions in English, some had language barriers. In total, twelve in-depth, semi-structured, face-to-face interviews were conducted with households, eight prior to installation, and four at a later date.

First interviews took place in May/June and August (Winter), and second interviews in November (late Spring). All were conducted in participants' homes. In-home interviews included observations of aspects of the home such as size, maintenance, window coverings, draughtiness, and age/efficiency of appliances. The research was conducted in accordance with the requirements of Swinburne University's Human Research Ethics Committee. Recognising the sensitive nature of the research, the researchers took care to ensure participants understood the intent and conditions of the study before conducting interviews. Prior to each interview the participant was given an information statement, had the research explained to them in detail, and signed a consent form. Participants were also advised that they could stop the interview at any time, and were not obliged to answer any question or provide any details they were not comfortable with. All interviews were recorded using a digital voice recorder, and lasted 30-60 minutes. First round interview questions covered motivations for installing PV, energy affordability, participants' experiences of managing electricity in the home, capacity to adapt household practices and routines, and tenants' expectations for PV. Second round interviews covered any changes to the household and their routines, and bills. During second round interviews a researcher guided participants through using the 'mySolar' app on their smartphone. Interviews were scheduled in advance at a time to suit participants, however, in one case the participant was not home and forgot the appointment. Also, two interviews had to be re-scheduled due to late cancellations. In another case the scheduled interview had to be cut short due to double booking, as the participant had arranged a dental appointment at the same time. These observations indicate that these women are juggling multiple priorities.

The interview schedule is appended (Appendix B).

Interviews were professionally transcribed[30] and thematically analysed using NVivo, Computer Assisted/Aided Qualitative Data Analysis Software, to draw out key themes

[30] Interviews were transcribed verbatim so as not to alter the participant's meaning.

across the case studies (summarised in section 5). Measures have been taken to ensure participants' anonymity in the reporting of this research, including changing participant's names and identifying details, and referring only to suburbs or regions where participants live.

2.4. Household electricity data

The study design included monitoring of actual energy consumption before and after installation[31], and solar generation.[32] All dwellings have an advanced meter installed ('smart meter') which registers and transmits data about a household's electricity use in real time to the electricity distribution network operator (distributor). There are five electricity distributors in Victoria: each is responsible for a separate geographic region[33]. PowerCor and Jemena are responsible for the electricity network in the western suburbs of Melbourne where this study is located. Household electricity data is collected by the distributor and retailer to manage electricity usage. Each household is billed individually for electricity (and gas, where applicable) by their selected energy retailer/s.

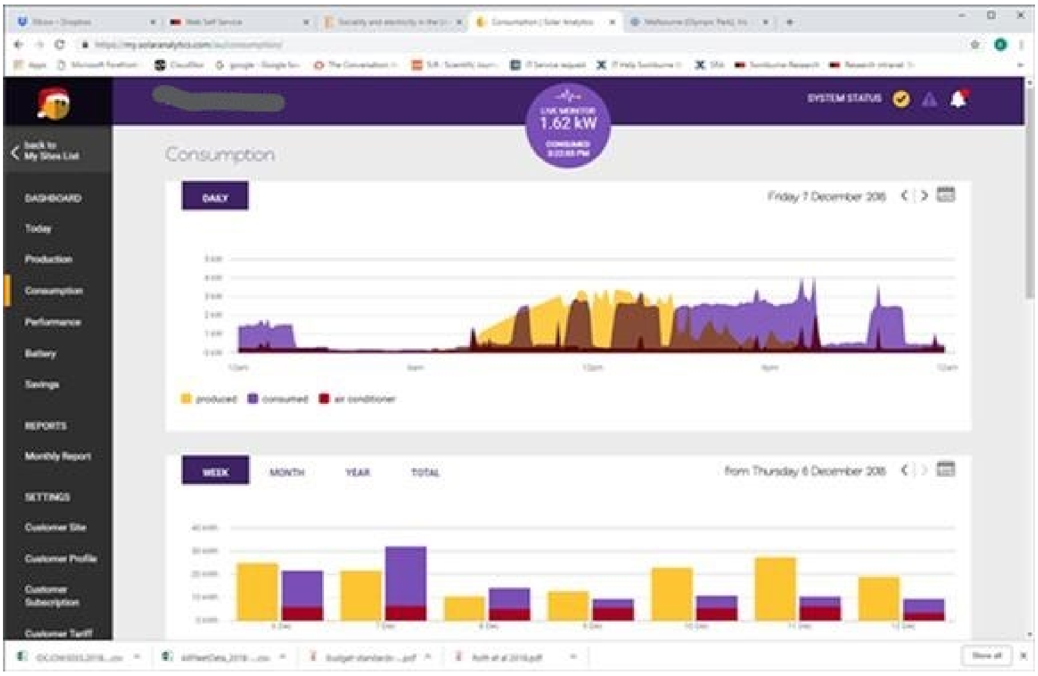
Written permission was provided from participants to enable researchers to obtain household electricity consumption data for the previous 12 months from electricity distributors. Whilst this process was relatively straightforward for PowerCor (4 households), it was not possible to obtain household electricity consumption data from Jemena (3 households) due to significant delays in communication from the distributor, followed by requirements to obtain further written permissions and for Swinburne University to enter into a data agreement. Due to data accessibility issues, these (3) households could not be included in the quantitative analysis.

To understand how household's practices may change to optimise self-generated electricity, the research design included installation of three channel Solar Analytics monitors in individual households to collect electricity production and gross consumption data in 30 minute intervals for all monitored circuits. The Solar Analytics monitors collected total solar electricity produced, gross electricity consumed as well as electricity consumed by the reverse cycle heating/cooling. Data was downloaded via the Solar Analytics online portal and analysed by the researchers. Participants were provided with access to their own live data dashboard through the Solar Analytics 'MySolar' app (Figure 2.1) or the website via their smartphones so they could monitor household solar generation and electricity consumption. Due to delays in installation of PV, difficulties in engaging a contractor to fit the monitors, and inability to access

[31] Historic household electricity consumption data was analysed using where this was available through the electricity distributor.
[32] Solar Analytics monitors were installed 'behind the meter' in individual dwellings by an electrician after installation of PV to monitor solar production and gross electricity consumption, and reverse cycle heating/cooling on separate circuits.
[33] For further details see https://www.energy.vic.gov.au/electricity/electricity-distributors

distributor ('smart meter') data for some households, monitors were installed in 4 of the 8 participant households.

Figure 2: Solar analytics dashboard – production and consumption



Source: Solar Analytics

2.5. *Temperature data*

Hobo UX100-003 Temperature/Relative Humidity data loggers were placed in the main living area of seven dwellings to record internal temperatures and moisture levels. The sensors were set to record every 15 minutes. The sensors recorded temperature and relative humidity within 3.5% accuracy. Data was downloaded from the sensors by the researcher team at the end of the study period.

Data loggers were placed in a suitable location in the main living area by the researcher at the first interview. Data loggers were collected at the second interview, or returned by mail by the householders, and data downloaded by the researcher. One of the data loggers was moved by the occupant during the study period (Dwelling 1), and another was put in a drawer by the occupant, as she thought it might get damaged (Dwelling 4)– leading to spurious data, so only limited data is available for Dwellings 1 and 4. One of the data loggers was lost, so no data is available for Dwelling 2. A summary of temperature and humidity data is provided in Appendix D (Table D1).

2.6. *Energy efficiency audits*

As part of the assessment of suitability for installation of PV and as a preliminary to this study, an energy efficiency audit was conducted for each property, commissioned by the housing provider, using the Victorian Residential Efficiency Scorecard (the Scorecard) – a voluntary home efficiency rating tool[34]. The audits provide baseline information about the dwelling and relevant features affecting energy performance and occupant comfort. The audit collected data on household physical characteristics including size, building type and material, lighting, space heating and cooling systems and appliances to determine the star rating (energy efficiency rating). Non-fixed appliances like fridges and washing machines are not included.

Table 1 Dwelling size and construction

No.	Type	Floor area (m2)	Space heating	Hot water	Electric reverse cycle heat/cool	Scorecard rating (out of 10)[1]	Envelope rating (out of 5)[1]	Easy to keep cool (out of 5)[1]
1	Split level apartment	68	Elec	Elec	Y	5	3	1
2	Separate dwelling	115	Gas	Gas	N	6	1	1
3	Separate dwelling	96	Elec	Gas	Y	6	2	1
4	Separate dwelling	120	Gas	Gas	Y	5	3	2
5	Unit	106	Gas	Gas	Y	5	1	1
6	Unit	66	Gas	Gas	N	7	1	1
7	Separate dwelling	70	Gas	Gas	Y	6	2	1
8	Unit	77	Gas	Gas	Y	5	1	1

Notes

[1] *The higher the rating score, the better the energy efficiency and performance.*

Dwellings range in size and age, but are predominantly detached or attached single-storey dwellings, mainly of brick veneer construction, built within the previous 50 years and ranging in floor area from 66 up to 120 sq.m. One of the dwellings is a split-level apartment. The majority of dwellings are connected to a gas and electricity source: six of the eight dwellings have gas space heating and seven have gas hot water, but in dwelling number 3, the gas room heater had been disconnected for safety reasons; electricity is the only source of energy for heating and hot water in one dwelling. None of the dwellings in this study had solar hot water systems. All but two have a reverse cycle heating/cooling unit installed. One family had a portable air conditioner, and others used portable heaters or fans for supplementary heating/cooling. Also,

[34] https://www.victorianenergysaver.vic.gov.au/scorecard.

researchers noted during interviews that some households had older and low rated energy inefficient appliances e.g. fridge, tumble dryers, portable air conditioning unit.

Energy audits revealed wide variations in energy usage between households for heating, cooling, hot water, and lighting – which is to be expected, given the variation in dwellings and number of occupants. For the dwellings in this study, energy efficiency performance as rated by Scorecard was between 5 and 7 (out of a maximum of 10). Dwelling number 5 has the highest rating (7) – this is the smallest (2 bedroom unit, area 66 sq.m) with gas heating and hot water, and no fixed air conditioning. Envelope rating for energy efficient construction ranged from 1 to 3 (out of 5) denoting poor to average performance, and thermal comfort level of 1 for all but one of the dwellings, which is low. The maximum rating for ease in keeping cool was 2 (Dwelling number 4). This indicates that all of the dwellings are difficult to keep cool in hot weather. Analysis of monitored electricity consumption data (Appendices C and E) indicates increased usage of reverse cycle unit on hot days.

The varying housing contexts allow for monitoring and evaluation of performance of PV across various domestic settings, and the benefits and challenges of intervention across dwellings of different size and attributes.

3. Limitations of the research

3.1. Size and nature of sample

This study is based on a small sample of Australian households living in cooperative rental housing in the western suburbs of metropolitan Melbourne, Victoria. This research aims to provide insight into the lived experience of the financial and other challenges faced by low-income households, and their exposure to solar PV. It is not, and was not intended to be, representative of a wider sample.

The sample size and in-depth qualitative approach enables the capture of rich and complex participant experiences with the take-up and use of PV within community rental housing, and is supported by detailed consumption data on individual households. Although the size and composition of the sample may limit the wider generalizability of the findings, nevertheless, the advantages of this approach should not be overlooked: it is most important for topics like the study of consumers of PV across selected socio-economic contexts where research knowledge is limited – as in this case. This pilot study demonstrates the importance of consumer research and feedback to inform policy effectiveness in the distributed energy market, and the challenges involved in the installation of PV systems connected to the grid for participating in electricity generation, and assist towards formulating appropriate responses to build resilience against rising energy costs. This pilot project also provides an opportunity to test the methodology and develop an approach to evaluate the benefits and costs of PV for community rental housing more widely.

Due to issues with data access and other limitations on scope and resources the pilot is not a randomized control trial and did not include a control group to control for seasonal weather variations and other effects. However, this approach has been used elsewhere and may be appropriate for a larger scale project. The research design for this pilot is an in-depth study of selected households, which compared electricity usage for a specific period in 2017 and 2018. The average temperatures for the study period (October-December) are not significantly different between the two years (Appendix D Table D1).

3.2. Application of findings to other social rental housing

In Australia, cooperative housing is a form of non-governmental, not-for-profit community housing providing rental housing for low to moderate income or special needs households, managed by community-based organisations that have received capital or recurrent subsidy from government[35]. Rental Housing Cooperatives (RHCs) are a distinct type of community self-managed, affordable housing for lower income families[36]. As such the organisational structure and resources, and profile of tenants may differ from those in other forms of community housing. Conclusions and recommendations take into account the cooperative ethos and tenant profile of participants, and may not be applicable to other social rental housing with alternative governance models and tenant/landlord relationship. However, some recommendations may be transferable to other housing contexts and cohorts.

3.3. Installation challenges

Delays in installation of PV for two sites due to the housing provider having to work through institutional and regulatory issues meant that electricity data could not be collected for these households. Other installation challenges included failure of the responsible persons/authority to complete meter configuration for three of the eight sites following installation.

3.4. Access to electricity data

Accessibility to household electricity smart meter data for analysis and evaluation is a significant limitation to conducting research in this domain. There is no standard procedure – and each distributor has different requirements. Despite participants' providing their written permission for the researchers to obtain electricity consumption data from the distributor, and assurances that ethical procedures had been put in place to maintain participants' privacy and confidentiality of data, one of the distributors (Jemena) would not release household electricity data (for 3 households in the study). The lack of availability of

[35] Productivity Commission (2011).
[36] CHIMES (2018).

reliable and systematic household electricity data is a major obstacle to being able to understand each household's consumption patterns and developing appropriate workable responses for reducing energy hardship.

3.5. Verification of energy expenditure and other information

Requests to provide energy bills had limited success. Numerous requests were made to participants who were asked to provide energy bills over a specified period of time, i.e. one year. However, most participants did not keep a record of utility bills, or account holders received bills electronically either monthly or quarterly by the retailer, and these were not made available to the research team. Only one household provided any billing information – this was for a single billing period (23 September to 23 October 2018). As no other details of usage or tariffs could be obtained from the participant households, it was not possible to verify consumption and actual cost. Calculation of cost and savings is therefore based on a theoretical rate.

There may be some inaccuracies in the data due to reliance on participant self-reporting of past events and current circumstances.

The next section outlines key issues associated with take up of rooftop PV in low-income rental households and implications for affordability based on a desktop review of the relevant literature. This is followed by findings in sections 4 and 5 which are based on analysis of interviews and observations made during visits to the participant households, together with electricity consumption and solar generation data, and draws on information collected during the energy audits.

4. Key issues facing low-income households in cooperative rental housing

4.1. Energy hardship and disadvantage is growing

Energy affordability has become a growing policy issue across Australia as energy prices have risen rapidly, with low-income households amongst those most at risk from rising energy prices[37]. Although historically amongst the lowest wholesale and household energy prices in the world, [38] Australia now has one of the highest energy prices compared to other countries. According to CPI, prices in Australia have increased dramatically over the past ten years, with prices faced by many small electricity users in the National Energy Market (NEM) have risen between 80 and 90 per cent (in real terms) to July 2017, raising serious affordability concerns for households and small businesses.[39] Migrants, low- and fixed income

[37] See ACOSS (2013); Cornwall et al (2016); Chester (2013)
[38] According to OECD data, Australia has dropped from the 4th cheapest and below the OECD average in 2004 to the 10th cheapest and above the OECD average in 2016.2 Other analysis has suggested that Australia's prices were close to the most expensive in the world. ACCC, (2018), Final Report Appendix 12.
[39] ACC 2017.

households, sole parents and families with children are more likely to experience energy affordability issues[40].

While disconnections for non-payment declined in 2015-16, rates steadily increased in 2017 (particularly for electricity), with 46,083 residential electricity and gas disconnections in 2017[41] [42]. The number of customers participating in hardship programs continues to grow and the level of debt is high. Some 80,000 customers participated in hardship programs during 2017, and the average debt to retailer of customers on those on programs was $1,564. In the first quarter of 2014-15, there were just over 23,000 customers in retailer's hardship programs but in December 2017, that number had grown to 37,935[43].

Energy hardship is caused by a conjunction of factors – low income, higher energy prices, the quality of housing, and capacity to adopt different practices to manage energy use given household size, composition and needs[44].

4.2. Take up of solar PV – participation gap in rental households

A sustained rise in consumer electricity prices has provided many residential consumers with greater incentive to choose how their electricity demand is met and to become active participants in the energy sector by adopting rooftop PV. Previous research shows that most Australian consumers install solar PV to reduce energy bills and to reduce their reliance on energy from the grid[45].

The focus of many community-scale renewable energy initiatives in Australia has been on recruiting individual homeowners. A participation gap has been identified for low-income households and tenants in rental housing who may not have access to or experience of PV to optimise energy use and reduce household energy costs[46]. Around 20 per cent of the Australian population now use solar for their electricity (15 per cent in Victoria)[47], however, there remains almost 80-85 percent of the population who have not participated to date despite the financial incentives to uptake PV.

Survey data reveals a clear socioeconomic gradient in household solar installations, with homeowners and mortgagees around seven times more likely to have solar panels in 2015–16 than renters[48]. Over one fifth (22%) of households in

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[40] ACOSS (2013).
[41] Essential Services Commission 2017:59.
[42] AMES Australia,*Submission to ACCC Issues Paper*, June 2017,p.2. PIAC found in a survey on disconnection that disconnection was about more than the bill but about several demographic factors working together. Such factors include, but are not limited to, having a medical condition, mental illness, intellectual disability, being a new migrant, unemployment, and speaking a language other than English. Their findings supported 'the conclusion that people who get disconnected have often faced multiple sources of disadvantage' (ACCC 2018).
[43] Essential Services Commission (2017).
[44] See Chester (2013); Azpitarte et al (2015).
[45] See Bondio et al (2018); CVSC (2013); Energy Consumers Australia (201)6; Romanach et al (2013)
[46] See Chester et al (2018).
[47] Clean Energy Council (December 2018).
[48] ABS (2017)

the highest wealth quintile had solar panels, compared with very low take-up (3%) of solar in the lowest quintile. This difference is partly due to lower home ownership in low wealth households. Wealth (driven by home ownership) has a stronger relationship to whether or not a dwelling has solar panels than income. Previous research asserts that financial capacity and home ownership are important pre-requisites for take-up of PV[49] along with groups of people who are unable to install PV due to tenure e.g. renting[50]. Systemic challenges for increasing energy efficiency in low-income rental households may be summarised as: lack of access to capital for purchase, split incentives and strata arrangements, and conflicting or complex information[51].

Evaluation of government programs indicate that motivation by Australian low-income households to adopt energy efficiency measures is driven by awareness, low perceived cost, incentives and rebates, comfort and health/wellness/stress [and] the top five barriers were high perceived costs, knowledge gaps, lack of trust, split incentives and low literacy/cultural barriers[52].

4.3. Actual benefits of solar PV are unclear – due to limited evidence

Research on residential solar adoption and integration, while growing, is still in its infancy. Despite awareness of the general importance of socio-economic variables, there remains a knowledge gap about PV and low-income households. There is limited research on consumers' uptake and use of PV particularly amongst low-income groups and the rental sector. Previous research on retrofitting renewables in low-income housing in Australia has focused on social housing[53]. In the Australian context, the role of cooperatives tends to be limited to self-organised community groups for energy purchase e.g. wind turbines (e.g. Hepburn Wind), solar purchase (e.g. MASH, Moreland Energy) and government programs (e.g. Solar Cities) which have not specifically targeted low-income rental households. Given potential equity implications of Australian residential PV policy further research involving low income tenants is warranted[54].

The actual benefits from generation and consumption of solar electricity may be less than expected. Previous research indicates a 'PV rebound' effect[55] i.e. a reduction in potential savings from PV due to higher overall electricity consumption, either in the form of more hours of use or a higher quality of energy service e.g. increased use of mechanical cooling, or heating the home to a higher

49 See ABS (2012, 2015); Sommerfield et al (2017).
50 See Byrnes & Brown (2013).
51 ACOSS (2013);
52 Russell-Bennett et al (2017).
53 See review by McCabe et al (2018)
54 Chapman et al (2016).
55 The Rebound effect or take back captures the idea that decreasing the marginal cost of energy by making it cheaper and/or more abundant through investment in energy efficiency may encourage increased usage of energy. For some households there may be a "solar rebound effect." As with energy efficiency, solar system installation may present occasion for a take-back effect as it may reduce the marginal cost of energy to the consumer.

temperature[56]. PV directly reduces the marginal and/or average cost of the energy itself, rather than reducing energy consumption for a given service, as in energy efficiency interventions. The impact on the cost of service for the customer, though, is similar to energy efficiency in that the installation of a solar PV system impacts the customer's total, average and marginal costs of energy. The rebound effect is most commonly expressed as a percentage. Whilst the rebound effect is difficult to quantify due to large variation between energy efficiency improvements, availability of evidence and evaluation of previous studies of rebound estimates direct rebound effects to be around 10 per cent or less.[57] However, rebound is likely to be higher for low-income households experiencing energy poverty – and unable to keep the home as warm or cool as they would like, because of high energy costs or the building condition (or both). A rebound effect of 15 per cent means that 15 per cent of the energy reduction initiated by the solar is offset by increased consumption[58] Analysis of PV consumption data for a representative sample of 4,819 households in New South Wales showed that installation of solar PV triggered a measurable increase in electricity consumption as shown by the estimated rebound effect. Analysis revealed that installation of PV while potentially reduced electricity consumption from the grid by 25 to over 40 per cent, also triggered a measurable increase in electricity consumption as shown by the estimated rebound effect of between 17 and 21 per cent (depending on tariff, with higher tariff having higher rebound)[59]. Households adopting PV in Alice Springs through the Alice Solar City initiative showed that systems successfully reduced reliance on the mains grid, reducing electricity usage by 34 per cent, but with PV adopters having a 15 per cent rebound effect[60]. A rebound effect of 15 per cent means that 15 per cent of the energy reduction initiated by the solar is offset by increased consumption[61]. However, even if total rebound is 15 per cent, then this equates to 85 per cent reduction in electricity consumption from PV. In the context of this pilot study, it is likely that rebound effects will reduce the overall benefit of any electricity/cost savings achieved from using self-generated solar electricity. The rebound contributes to increased consumer amenities such as more comfortable homes, improved quality of life; these savings are not lost but put to generally beneficial use (i.e. indirect benefit to health and wellbeing).

In terms of other benefits to households, key findings of research by Curtin University[62] showed that low-income households in Western Australia that have been able to benefit from the installation of solar panels, spoke of the reduced

[56] The solar rebound effect encompasses the idea that a certain percentage of residential solar generation is taken back by households in the form of higher overall electricity consumption (Herring and Roy 2007: 195).
[57] Nadel (2012).
[58] Berkhaut et al. (2000: 426).
[59] Deng and Newton (2017).[59] Havas L and Race D. 2015. Enhancing household energy efficiency in central Australia: Analysis of the Alice Solar City initiative. CRC-REP Research Report CR001. Ninti One Limited, Alice Springs.
[59] Berkhaut, et al. (2000: 426)
[60] Havas L & Race D. (2015)..
[61] Berkhaut,et al. (2000: 426).
[62] Cornwall et al (2016).

anxiety they felt with regards to their energy bills and the greater feeling of involvement it gave them in the management of their energy expenditure.

4.4. *Effectiveness of smart digital technologies in aligning household practices with electricity production*

Smart digital technologies used to provide feedback in conjunction with solar panels have significant potential to change household energy practices, in particular visual displays providing real time information have been shown to influence how households think about and manage their electricity use. Home energy monitoring devices and software applications for mobile phones are now available to monitor solar PV generation and household consumption, however, these are not widespread in Australia, and there is a scarcity of research on use of mobile applications for visualising and managing real time electricity consumption in PV households. Further evidence is needed on whether and how energy feedback, especially that enabled by digital technologies, could influence behaviours to optimise solar PV energy use and reduce energy poverty in low-income households.

Feedback systems play an important role in making energy consumption visible. A qualitative study of 28 Australian households participating in three separate In-Home Displays (IHDs) feedback trials found that IHDs are an important visualization tool that can raise awareness of the consumption flows through the home, as well as reposition responsibility for energy management onto householders[63]. Research across a range of households in the UK found that digital IHDs were positively received, easily understood and actively enrolled into managing home, budgets and household life. In this large-scale trial PV participants with import/export IHDs (n= 101) referred to the use of colour coding in the IHD display as being particularly powerful in reshaping household practices. The indications are that IHDs are associated with changes in household practices that require use of appliances, such as dishwashing, laundry and chores, and to a lesser extent cooking, which are shifted to daytime when electricity is being generated on-site[64]. However, other research suggests that effectiveness is dependent on how readily users understand and engage with the technology[65]. The impact of feedback displays, particularly for women, can be enhanced by the development of a supportive social environment[66]. Further analysis is required to verify the extent to which visualisation of electricity data in real time supports shifts in habits and routines and use of self-generated electricity on site.

Real-time feedback has higher impact on consumption than other feedback channels such as web pages and informative bills[67]. Previous research has found

[63] Strengers (2011).
[64] See Vine et al (2013).
[65] Buchanan et al (2015).
[66] Burchell et al (2016); Darby (2010).
[67] Reviews of consumption feedback suggest that IHD has varied success rate of 0-20 percent. See Lewis et al (2015); Zhang et al (2019).

that IHDs are valuable as a source of feedback and information, contributing to understanding what specific appliances use energy, how much energy is being used at different times of the day/week, and overall spending. A study in South Australia[68] indicates that feedback displays may assist occupants understand their end-use energy behaviour, reduce their net energy use, and assess whether household appliances and energy systems are operating correctly. Research in the UK showed that IHDs can assist with 'good housekeeping' – knowing what is coming in/going out and managing the household economy and finances. Households using IHDs are able to identify new optimal alignments between PV power generation and household practices not previously recognised. As such, IHDs demonstrated they are effective in making practices flexible in ways that support the use of more self-generated electricity[69]. In another small study of 7 households in the UK, tenants received solar panels and energy monitors from their social landlord; the monitors offered a helpful visual cue to households that they were generating solar power even if outside there was no sun – assisting households make more effective use of the solar electricity. However, lack of engagement was an issue for some.[70] The evidence suggests that potential exists for digital feedback devices to facilitate and support localized energy provision – but this has not been widely explored in the social rental sector for reducing energy poverty.

Whilst direct feedback, including visualisation, has been shown to influence household energy consumption, the use of apps to manage energy is a relatively recent technological innovation. Compared to dedicated in-home displays, smartphone/tablet apps provide a low-cost and simple design solution for making energy feedback available. In a large trial in Dutch households, users reported increased awareness and energy-saving. People used the apps mainly to learn how their energy consumption levels are built up and to monitor the consumption levels over time, rather than to decrease one consumption levels. Effectiveness can be linked to a higher use frequency and insights relevant to the goals the End users want to achieve in their household.[71]

In terms of smart technologies that go beyond encouraging households to solely save energy, there is little published research on whether visual displays via a smartphone or other device can enable users to adjust their electricity consumption patterns to the demand and supply of (local and renewable) energy.

4.5. *Capability and flexibility are critically important in changing household behaviours to optimize self-generated electricity*

Previous research points to the importance of integration of solar generation into household routines and practices – that is, being able to make use of self-

[68] Whaley et al (2013).
[69] Bulkeley et al (2014)
[70] Fox (2016).
[71] Geelen et al (2019).

generated electricity and ability to adapt household routines. Capability and flexibility in changing routines are both significant. Capabilities are influenced by household characteristics such as age, sex, disability status and educational attainment[72]. The use of electricity and flexibility is shaped by capacities, conventions, rhythms, economies and societal structures[73].

5. Research findings

Based on the interviews, a number of themes can be identified from the qualitative analysis, which are illustrated with quotations from participants. All but one of the interviews was conducted in English. Six of the eight participants are not native English speakers and had some language barriers, Quotations are reproduced in participants' own words and have not been changed to correct expression or grammar, so as to avoid changing the meanings.

5.1. Households are trying to manage family needs with energy stress and hardship

As previously indicated, households on low and fixed income, sole parents and families with children, and those from migrant backgrounds are more likely to experience energy affordability issues. In this study, participant households are all sole-parent families – amongst the most disadvantaged groups in Australia. Parents/carers with young children, and those at home during the day have comparatively higher levels of energy consumption, because they occupy the dwelling for a greater number of hours. This study includes two infants under 1 year, five children under 5 years, and at least five adults or children with a health or other condition (e.g. asthma, autism), which increases energy needs for space heating and/or cooling, bathing and laundry. As the findings below suggest children's needs take priority:

> *...washing machine - it's hard to reduce because my son, he goes to kinder four days [...] I wash all day, bed sheets Saturday Sunday, all their uniforms, my clothes, their clothes [...]. (Ursula)*

> *I've used the central heating at night, because obviously the little one needs to be warm, so I keep it at 18 or 19 at night. (Abby)*

> *My younger child. ... he is a bit hyperactive so he doesn't listen to instructions often. So he'll often run and do things. ... when it's cold he insists on turning on the heater. If the weather gets hot, he insists on turning on the air conditioner. It's not really about health. ... he's physically very active so when he's hot he can't put up with the hotness and he insists on turning on the air conditioner. (Grace)*

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[72] ABS (2011) Measure of Socioeconomic Status 1244.0.55.001 http://www.ausstats.abs.gov.au/Ausstats/subscriber.nsf/0/367D3800605DB064CA2578B60013445C/$File/1244055001_2011.pdf

[73] See CCRES framework in Bell et al (2015). The model is able to connect the intersecting routines, temporal and spatial mobility (structures and rhythms) with appliances, including competency in their use (capacities and economies) that are in turn implicated with notions of accomplishment and identity, cultural expectations (conventions).

Households with children, and those with a health condition or special needs required more use of energy, particularly in winter:

> *Well, my daughter has got asthma, and that flares up more in the winter than in the summer, but yeah, when it's very cold for her she coughs a lot. … I don't let it drop below a certain temperature, otherwise she starts off coughing. (Abby)*
>
> *My son's autistic and, in the morning, when it's cold, he just doesn't do anything. He just lays there, going, "It's cold." After a shower, he'll just turn himself into a little ball on the floor, with a towel over him, and not move. (Aimee)*
>
> *I find winter the most difficult time of year. Summer, it's easy to keep cool. You go play with water outside, you close the blinds, the house keeps cool pretty well, reasonably well. But it's winter that's the most costly with two young kids, you really don't want them getting sick frequently either so you do have to manage the temperature of the house. (Hannifah)*
>
> *So, I literally just use a dryer for everything. I use tumble-dryer a lot. Pretty much every load […] my son – he wets the bed every time. (Aimee)*
>
> *If [the laundry] is not getting dry during the daytime, I bring them in and turn on the heater so it dries in time. (Grace)*

Social or cultural practices may also influence how energy is used in the home:

> *So culturally … I don't like wiping dirty bottoms with wipes, so every time they do a number 2 we go shower and wash. Just a quick one, two minutes wash so I know that it's probably clean and he won't' get a rash. I know it's different, you guys usually just use wipes - I know in the childcare centre they just use wipes. So that's where our water's being used quite often, and being winter, you need the hot water. (Hannifah)*

As indicated above, participants identified 'non-negotiable' needs, which may be for health or cultural reasons. Very often washing and drying laundry is scheduled so that children have clean clothes for school the following day/week. Where these activities occur in the early morning and/or evening, PV would not reduce this electricity consumption – unless these activities could be adapted or shifted to a time when solar is generating.

All but one of those interviewed indicated that they have previously had or are currently experiencing energy affordability problems with difficulty in managing large or multiple energy bills, compounded by accumulating previous debt. Participants related having experienced "bill shock", anxiety or financial stress, and six had opted for payment plans with their retailer:

> *So when I moved in here, what I struggled with was gas. Gas was so expensive. That three-month period of winter, apparently my case worker says it's a normal price but it shocked me. It's $400, nearly $500 for gas with that much. But I think I used a bit too much of the central heating. (Hannifah)*

> *I know – they say you get more discount if you put both, but I can't monitor it. So what I'm worried about, if I put both onto Lumo, gas and electricity, every month or every three months I'm going to have this bill or a massive shock because I can't monitor it. (Hannifah)*

> *Before I was often stressed [...].I just stopped my medication for depression half a year ago [...] my younger kid is very hyperactive so that really stresses me out. When I see a bill or a large bill, I'm very stressed. (Grace)*

One participant still had outstanding energy bill debts for her previous house and was on a payment plan:

> *When I moved into the [previous house] there was a problem with the heater there, and it was using three kilowatts an hour, so my monthly bills were $900 for that place because I had to have the heater on because of the baby at night. [...] They [housing provider] did eventually fix the heater, but I still got left with the bill. ... I'm paying that one off with a payment arrangement now. (Abby)*

Participants consciously use various strategies for managing household bills, such as putting a sum of money aside each fortnight and having a separate bank account for paying bills:

> *My budget for bills is $100 for electricity, $100 for gas, $100 for water a month. If it goes over that, then I'd be a bit concerned. [...] I'm on Centrelink so you know exactly what you're going to get to the cent ... So once you know exactly what you get, then you do your budgeting from that. (Hannifah)*

> *I transfer money across every fortnight. I'm very good at budgeting. ... and I transfer – I'm probably putting across $50 a fortnight to my bill account. And then, when the bill comes, I pay it. (Aimee)*

> *I have card – it's a finance card – it's $550. ... like this fortnight I'm going to pay the cards, and internet and next fortnight I'm going to pay two bills like half/half and then I leave some money for the shopping, for the kids. Every fortnight like this. (Aisha)*

In one instance, the participant made a decision to pay the outstanding electricity bill and delay medical treatment for her son:

> *I didn't pay the money on time and then they told me they would cut off the electricity. ... Then I called the office and they just tell me, "We don't have a problem.*

Just you have to pay that money." I said, "Okay. I have only $300 and there is no 75." They told me, "Okay. You just pay this $300 now and we'll leave you the electricity and then next fortnight pay for the $75." [...] And then I do that then they leave the electricity, they not cut it. But that time I was saving that money to my son. That time I called the doctor I said, "No. Next fortnight I bring my son." [...] because he's every month to see the doctor, every month because he has seizures. (Bina)

Delaying payment or arranging a payment plan with the electricity retailer is a common strategy for managing large utility bills.

There's so many bills to pay and they come at the same time. I often call people to ask for a delay in the due date. (Grace)

When I see the money is not enough, I call the company and I pay like every fortnight until I finish the bill. (Bina)

So when the bills come and I see that I can't afford to pay, so I call AGL people and I say if they can delay the due date by a month and they say "Yes" so when the time comes, they just direct debit my account. (Grace)

I'm paying quite small amounts, because I'm not on a very high income. Yeah, it will take me ages. ... So, it's $1600 or something I have to pay off. (Abby)

... when I see the money is not enough, I call the company and I pay like every fortnight until I finish the bill. Like last time I do with AGL they send me bill – this bill was overdue and I forgot to pay and then the bill, they come - it was $230 and they come $480. And then I called them, I say 'every fortnight I pay $100' and now I paid like $250. (Aisha)

I just called them, ... I pay every fortnight until I finish. But now, first I save for the bills, when I get paid, I manage my shopping, everything. [...] Yeah I call them. You know when you go for a lower plan, it's more expensive than the bill you get. You pay more. (Ursula)

Other coping strategies included seeking help from a charity in the past to pay a large electricity bill, and applying for a relief grant.

I applied for the government grant ...where they can put some money onto your overdue power bills, and I'm waiting for a decision. (Abby)

Interaction with energy retailers adds a further layer of stress. Several participants described how they had difficulty when contacting retailers to resolve problems such as being billed twice following moving house, or the incorrect meter number.

To reduce bills some households self-limited energy use, including using heating and cooling only for short periods. One tenant with two young children, who budgeted carefully and indicated that paying bills wasn't usually a problem, also had strategies for reducing energy use in winter:

> *…we go to the library, it's free heating, and there's always a program on, and my gym is right there too. So we do it that way. If I'm home and it's like crappy weather, I'll turn on the heater, but most of the time we just use blankets. (Hannifah)*

> *…from six o'clock in the morning because the kids wake up from six. I open it like half an hour or sometime one hour. After they warm and then we turn it off. (Aisha)*

Most heated individual rooms using plug-in heaters/fans in the morning or at night, especially for warming bedrooms and bathrooms for children:

> *… it's [oil heater] in the bathroom, for now. I might need to get another one for the kids' room. But, I don't worry about myself. I've got an electric blanket on there, but I don't really use it. But, the kids – yeah. I put the heater in there, for them. But, I don't like – it's too expensive to run. (Aimee)*

> *I have a small heater for the night – it's an oil heater. …before the kids go to the bed. They warm the room and then I turn it off … (Aisha)*

> *In a bedroom we have a small heater, we put it on before we sleep like maybe ten, 15 minute and then we switch it off because it's cold anyway, is winter. (Sera)*

> *So the plug-in … it's a fan during summer and it's a heater during winter, and it heats up the room perfectly, just one bedroom, … because it has a timer we can turn it off, we set it that way. (Hannifah)*

Sole parent households interviewed in this study are under financial pressure and consciously trying to restrict energy use from stress dealing with unaffordable bills and debt, with potential health implications:

> *I think I've probably been more careful about the heating because …when I was jointly paying bills with people [it's] been like, right it's cold and I don't want to be cold, put the heater on. But now I'm like, well I've got to pay for it by myself and there's all this other stuff to pay for, can we really manage without it being on? (Abby)*

Strategies to limit energy use had varying success, particularly in larger households and those with older or teenage children who turn on or adjust heating and cooling themselves:

> *I'm trying my best to limit energy use from my two children. Only when I need it I turn on things but otherwise I try to limit them. … they don't really listen to me (Grace)*

One participant used Powershop[74] mobile phone app to manage her electricity consumption and budget by pre-purchasing (i.e. advance purchase) electricity in packs when it is cheaper.

5.2. Quality of housing impacts on electricity consumption

Interviews conducted in homes revealed that the design and construction of the dwellings is a key factor in occupants' comfort and energy use. All participants expressed concern during first round interviews about very hot summers or cold winters and the need to use the air conditioner or heater[75]. Overheating in summer was a particular problem:

> *It does get really hot in here, so I have to use it [air conditioning] all the time, pretty much. … Like, when we get home from school until, maybe, bedtime. So, probably about four hours a day. (Aimee)*
>
> *… the house is small so in winter it's okay, not bad. If I turn on heater then it can warm up the house quite soon but in summer it's quite hot. (Grace)*
>
> *[Using the portable air conditioner in the open plan kitchen/living space] From 12pm until late in the afternoon because this faces the sun in the afternoon so it gets uncomfortably hot. (Grace)*

In two other cases participants specifically complained about the kitchen becoming extremely hot during summer, which made it difficult for occupants to cook during daytime (when the PV is generating) or store certain foods in the kitchen cabinets:

> *Kitchen in the daytime is the very worst. If you open the stove […] You'd never cook daytime … (Ursula)*
>
> *I've got the afternoon sun directly through that window and it just gets really hot in here [Kitchen/Living room]. Like, that cupboard above there used to be my chocolate cupboard, but everything would melt. (Aimee)*

Overheating during hot weather is confirmed by temperature monitoring. Analysis of temperatures in the main living room ranged from 9.1 °C (Dwelling 8) up to 31.8 °C (Dwellings 4 and 6)[76] (Appendix D Table D1). As indicated by the participants

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[74] Powershop is a subsidiary of Meridian Energy. Powershop offers an 'online supermarket' that allows customers to choose the cheapest available power, or different sources of renewable energy. Customers can also choose to purchase power for the future, and spread the cost of power over the year. For example, during spring, they might store up power for summer, ensuring they have enough to get through with no nasty bill surprises. Powershop's online platform and smartphone app keeps customers informed weekly, showing comparisons in their weekly usage and costs. Users can pre-purchase power packs and take advantage of special deals, making it unique in the Australian market. Currently in NSW, Victoria and South East Queensland,

[75] Melbourne's western suburbs has a Mild Temperate Climate (Zone 6) and experiences extremes in temperatures in both summer and winter. Both heating and cooling is required, which accounts for the highest proportions of energy bills

[76] Lowest temperature 9.1°C on 16 September 2018 (Dwelling 7); highest temperature 31.8°C on 31 May 2018 (Dwelling 4); 31.8°C on 19 November 2018. (Dwelling 6).

above, this impacts on timing of household activities such as cooking. In Dwelling 1 the maximum temperature in the main kitchen/living room was 29.9 degrees, and the temperature reached over 27 degrees for extended periods on 14 days during the 8-week monitoring period (25 per cent). During interviews researchers observed that poor thermal performance was often due to shortcomings in the design and construction, such as orientation (afternoon sun), lack of shading to main living rooms, and single glazing. Six dwellings have reverse cycle heating/cooling installed in the main living room. Yet, all participants mentioned that they use heating/cooling only for short periods until the house is sufficiently warmed up or cooled down and then turn it off, to try and avoid large energy bills.

Poor thermal performance is likely to exacerbate temperature extremes and in difficulty keeping the house at a comfortable temperature, particularly during hot weather (with accompanying requirement for mechanical cooling in the late afternoon and evening/night time for sleeping). Key issues contributing to poor thermal performance confirmed through energy audits included: lack of insulation in walls and roof; poor draught sealing of the building envelope; single glazing, and low efficiency heating/cooling and hot water systems. The energy audits recommended improvements to the building envelope for all dwellings in the study to improve energy efficiency and thermal comfort: these include increasing insulation to ceilings and walls, double glazing and installing weather sealing to dwellings.

Another design-related issue raised was drying the laundry: the lack of space both outside and indoors to hang the washing, and increased use electricity for drying laundry:

> *I do my washing and then put it in the dryer, because I don't have a clothesline at all here. And, you know, [the apartment] it's very small. I've got a clothes horse there, but I never use it. (Aimee)*

Another participant turned on the gas heating indoors to dry the laundry, as she did not have a tumble dryer.

Low internal temperatures, inadequate insulation, intermittent heating, moisture (indicated by high humidity) and lack of ventilation increases the risk of condensation, damp and mould – which can be a risk to health. Mould was noted in the bathroom of one property (Dwelling 5) which may indicate underheating or poor ventilation practices.

5.3. Using inefficient appliances reduces the benefits of solar

As indicated in section 5.1 above, some households continue to use low-efficiency appliances such as tumble driers and fan heaters to meet specific needs. Others had older, inefficient or defective appliances e.g. fridges, portable air conditioner, which undermines attempts to reduce electricity use, for example:

It's very old now so it [large fridge freezer] doesn't work very well .... So, everything in there gets frozen when I put them in, so now it's functioning as a freezer ... It's not doing its job well so I have another one, a small one [fridge] (Grace)

Supplementary heating by electric plug-in heaters was used frequently to heat children's bedrooms[77] for short periods. Five households used plug-in electric or oil heaters and a portable heat/cool fan in the bedrooms:

My daughter at night time if it is cold she cries, she doesn't want to sleep. [Interviewer: Okay and what do you do?] I just turn on the heater here before I buy the small heater in my room. (Ursula)

In a bedroom we have a small heater, we put it on before we sleep like maybe ten, 15 minute and then we switch it off because it's cold anyway, in winter. (Sera)

Use of supplementary heating/cooling indicates an inability to achieve thermal comfort –i.e. the building not reaching a comfortable temperature – which may be due to the lack of effective heating, or the inability of the building to stay warm due to poor energy efficiency. Using inefficient appliances can increase electricity consumption and reduce the benefits of solar PV for households. Monitoring and feedback can increase literacy about different household appliances and their energy consumption, and assist households to make informed choices. However, heating and cooling may be non-negotiable, particularly for children's health. Gradually replacing appliances with more energy efficient ones will reduce household electricity consumption. All of the tenants interviewed are living on a low-income, and energy efficient appliances tend to be more expensive than lower efficiency models.

5.4. Reducing bill stress and energy-related debt is the motivation for adopting solar

Participant households are financially constrained, living on a low-income and/or managing ongoing debt and have difficulty paying utility bills. All households in this study reported on-going stress and/or anxiety associated with paying their utility bills alongside other regular and unpredictable expenses. 'Bill shock' – getting a large bill or several bills at the same time is an issue experienced by households on a single income. Several participants also indicated that they have repayment plans for their electricity and gas, and others are making loan repayments for a car, or furniture.

Managing their household budget and paying their utility bill on time is a priority for most participants. Participants indicated during interviews that they paid between $100-$300 per month. Some though, receive higher bills particularly in winter. Financial management skills and strategies varied between the households. One strategy used to ensure bills are paid on-time and avoid stress was to set up a

[77] Temperatures in bedrooms were not monitored as part of this study.

bill account, and to transfer money to the bill account every fortnight: "When the bill comes, I just go, "Time to pay the bill," and pay it." (Aimee)

Although strategies include budgeting an amount per month for utility bills, if the bill is larger, then this becomes a problem as households may not have a safety net.

> *So, my budget for bills is $100 for electricity, $100 for gas, $100 for water a month. If it goes over that, then I'd be a bit concerned. (Hannifah)*

A lack of awareness of energy consumption is likely to translate into unexpected bills and potential payment problems, leading to energy-related debt. Most households relied on quarterly/monthly electricity billing from their retailer (with three participants receiving bills via email), but only one was able to provide details of their electricity tariff during interviews, whilst others (mistakenly) understood electricity to be cheaper at night. Only one participant regularly monitored electricity usage through the retailer's app to assist with household management:

> *To me, what's important is I need to be able to monitor on a daily basis, so Powershop emails me every week, giving me an update. I can always constantly check on my app what I'm using. (Hannifah)*

However, actively monitoring electricity usage on distributor/retailer web portals or mobile phone apps is not common amongst those interviewed.

A number of the participants were on payment plans. Due to late payment, arrears or poor credit rating some low-income households have limited options in selecting a retailer:

> *… because of my financial situation I don't have very many options … So, I have to go with who will accept me because of my credit rating. So no, Origin was the best of the ones that I could go with so that's where it'll stay. (Abby)*

Further, customers in arrears may not be able to benefit from retailer discounts, which are conditional on the customer paying on time. These discounts are achieved only 56 per cent of the time for payment plan customers and only 42 per cent of the time for hardship customers.[78] Customers who do not pay on time are, in effect, paying late payment penalties, often amounting to hundreds of dollars per year.

As most participants are having difficulty managing energy bills, the principal motivation for having PV is reducing electricity expenditure and debt. Environmental concern is not a high priority for these households. Three interview participants expressed environmental concerns, with one purchasing 100 per cent green power, but for most of the participants benefits to the environment is not a key motivation. This aligns with other recent research which indicates that

[78] ACCC (2018).

Australian households have been motivated to adopt rooftop PV because of rising household electricity costs, and meeting household electricity needs, followed by providing uninterrupted power, benefits to the environment and reducing reliance on energy retailers.

Electricity consumption and production

In this study, solar PV installations range in size from 3.2 to 5.4 kW, depending on the dwelling size, roof area/orientation, and expected household demand. Panels were installed predominantly on the north facing roof but where space was restricted, panels were also distributed across west and east facing roof slopes - with the potential to extend the daily generation period. As indicated in section 2.2, Solar Analytics monitors were installed to record each household's solar electricity generation and consumption, and overall electricity consumption for a period of 8 weeks during late Spring and early Summer (17 October to 11 December 2018). Details of solar electricity generation and export, solar electricity consumed and electricity imported from the grid is provided in Appendix C (Tables C1-C4).

Production

A summary of solar production for each dwelling is provided in Table C1. The total solar electricity generated ranged from 848 kWh to 993 kWh for the installations for the 8-week study period (Table C4). All but one of the solar systems performed within the normal expected system production. The Solar Analytics monitor indicated a 'zero production' fault in the solar system installed on Dwelling 6 that affected solar production, leading to cutting out when voltage exceeded the safety level.[79] This fault was reported to the housing provider.

Solar production was monitored using Solar Analytics monitors from 16 October 2018, and supply and export has been verified by comparison with data obtained from PowerCor where available. This report does not discuss the technical attributes or efficiency of the installations, but instead focuses on how managing consumption and production is evolving amongst community housing tenants as they incorporate the solar PV into their everyday routines, and implications for reducing energy poverty.

Table 5.1 Average daily electricity consumption and generation for study period

Dwelling	Consumption (kWh/day)	Solar generation (kWh/day)	Solar exported (kWh/day)	Electricity imported from grid (kWh/day)
3	14.38	15.36	10.68	9.70
4	12.51	17.33	11.85	7.03
6	15.22	14.61	9.89	10.51
8	7.35	14.76	11.25	3.79

[79] Personal communication with Haubert Yawenas, Senior Operations Engineer at Solar Analytics on 19 February 2019.

Consumption
Our analysis indicates that there is a wide variation in energy consumption between the households, with average consumption between 7.35 to 15.22 kWh per day over the 8-week study period[80] (Table 5.1), reflecting differences in house design, number of occupants, patterns of behaviour, and efficiencies of appliances and equipment. The household with the highest average daily consumption is twice that of the lowest. Estimated annual consumption 2017-2018 ranged from 4648 to 6163 kWh per year[81]. Typically, energy consumption is related to house size and type, number and age of occupants, patterns of occupation, income and appliances, together with external weather conditions (temperature and wind). Some households use higher amounts of electricity in the summer and winter months. This is probably due different space heating as several households utilise reverse-cycle heating/cooling with a high coefficient of performance. Households with multiple heating sources can select which appliance to use, to heat the whole house or individual rooms. Some participants reported that the gas heating is too expensive to use in winter and electric heaters are used to heat individual rooms as required. Very low electricity consumption (Dwelling 8) could indicate rationing of energy due to concerns about running costs or debt with implications for comfort and health/wellbeing.

Comparing the monitored consumption with historical electricity consumption for the same period in 2017, three of the four households showed an increase in average daily consumption over the study period of between 2 and 5.4 kWh per day (Appendix C Table C2). A comparison could not be made for Dwelling 8 due to data limitations. Whilst the aim is to reduce household bills by consuming electricity generated by the solar PV on-site, not all households showed a reduction in electricity imported from the grid over the period monitored. Dwelling 4 reduced electricity imported from the grid by around 5.4 kWh per day (averaged over the 8-week monitoring period). Dwellings 3 and 6 showed a slight increase (typically <1 kWh per day). Increase in consumption is due to the PV rebound effect as discussed in section 4.3.

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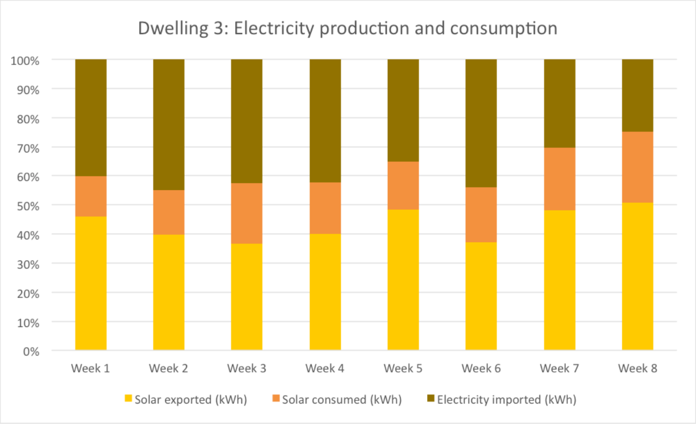
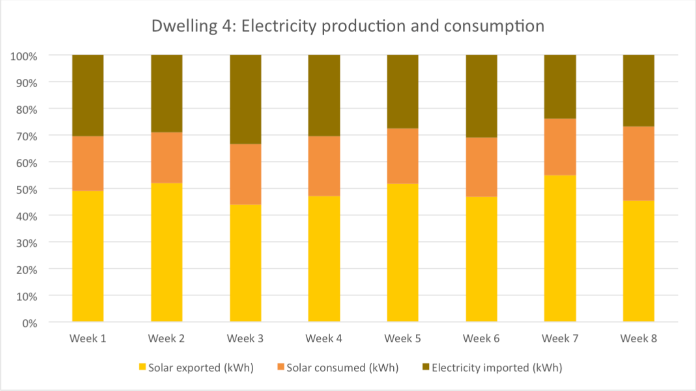
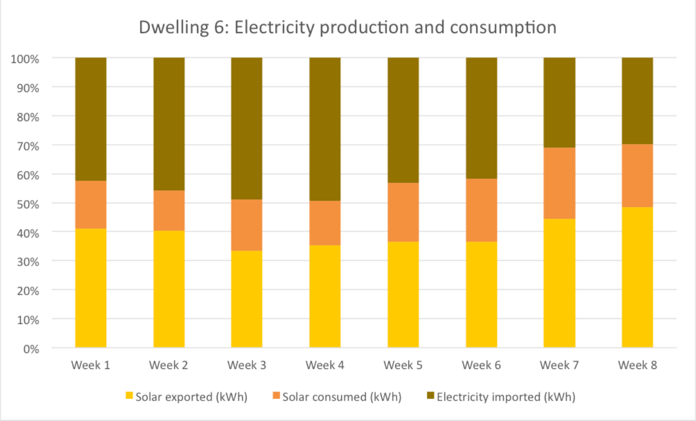
[80] 17 October to 11 December 2018 (56 days).

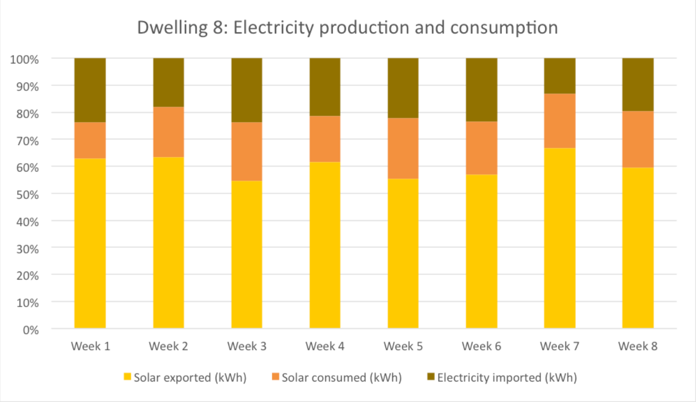
[81] Based on historical electricity data. PowerCor electricity supply data over 12 months prior to monitoring for Dwellings 3,4 and 6 show annual supply of 6163, 4648* and 5293 kWh. *Annual consumption for Dwelling 4 is incomplete as it does not include solar used on site from 13/06/2018 to 30/09/2018 (15 weeks 5 days) as solar consumption data is not recorded by PowerCor, only solar export. As a comparison, the average annual electricity consumption for Victorian households is 5413 kWh in PowerCor DSPN (Acil Allen Consulting 2018 p.19 https://www.esc.vic.gov.au/sites/default/files/documents/victorian-energy-usage-profiles-report.pdf). Historical electricity data for Dwelling 8 not available due to a change of tenancy/account holder.

Figure 5.2 Increase in solar electricity consumed on site over the study period









Despite the financial benefit to households for utilising PV generated energy on-site, our analysis shows average use of solar on-site between 24-32% of total generation (see Appendix C Table C1). Export amongst households ranges between 62-75% of generation over the period. The level of export from low energy users with a reduced base load demand can be as high as 82.4%[82].

However, as indicated in the Figure 5.1, all households did reduce export and the trend shows an increase in use of solar electricity on-site during the 8 week monitoring period. Dwelling 4 increased solar consumed on-site from 29.5% to 38%. It should be noted that Dwelling no. 4 has a relatively large solar photovoltaic system (5.4 kW) to offset expected household electrical load. In second round interviews participants reported increased awareness and changes in routines to make more use of solar electricity. The purpose of the Solar Analytics app is to assist households in visualising and using the solar electricity as it is being generated, increasing usage of on-site electricity. Analysis of consumption patterns using daily load profiles for dwellings at the beginning and end of the study period (Appendix E) indicate that households increased consumption of solar on-site, however, there is potential for further opportunities to increase the use of solar electricity and load alignment.

Financial benefits and costs

Appendix C sets out the current tariffs (Table C5) and electricity costs and benefits for each household (Table C6). Further calculation of net benefits based on various scenarios for solar usage, solar export and electricity import from the grid is provided in Tables C7-C9. The financial cost depends on the units of electricity consumed (kWh), tariff per unit of electricity, and the Service to Property charge (also known as the Daily supply charge). The financial benefits are calculated by adding together the self-generated electricity used at marginal cost (Indirect benefit) and the credit for feeding in excess solar electricity back to the grid (Direct benefit). Each household has a contract with a different retailer and Feed-in Tariffs vary, the lowest being 9.9c/kWh (Dwelling 3) and the highest is 13.5c/kWh (Dwelling 8). Dwellings 4 and 6 are both receiving a Feed-in Tariff of 11.3c/kWh. The savings plus credit calculated for the study period (17 October to 11 December) range from $117.21 (Dwelling 6) to $162.76 (Dwelling 4). This works out to be around $2.09–$2.91 per day (combined Direct and Indirect benefit) to off-set the grid supplied electricity costs (Table C6). Variation in calculated bill savings and Feed-in credit may be connected with tenants' understanding of PV systems, household practices, as well as differences in sizes of systems.

Financial credit for Feed-in is calculated, based on the assumption that approval has been obtained, and meter reconfigured to feed solar electricity into the distribution network. It should be noted, however, that three of the participant households did not receive the credit for feed in of excess solar as the meter had

[82] Dwelling 8, Week 1. Low on-site consumption (2.6-9.1 kWh per day) is likely due to the dwelling not being occupied for extended periods or because the householder was not aware that it was beneficial to utilise electricity generated during the daytime.

not been reconfigured to measure the units exported. This occurred due to failures between the installer/electrician, distributor and retailers to submit/process the necessary meter alteration request or because the pre-approval had expired[83] A lack of follow up by the tenants due to confusion about the process, and absence of clarity on who is responsible for oversight – whether the tenant or the housing provider, may be contributory factors. As of 31 May 2019 one participant was still not receiving credit for solar exported[84]. This has led to frustration, and potentially disengagement:

> *And it's really frustrating because I spent weeks giving Origin the paperwork and they said everything was fine, and then suddenly I got my bill and it [credit] wasn't on there so I called them back and said, "Oh no, we haven't set you up because the paperwork expired with Powercor on the 31st of October." (Abby)*

The benefits of increasing the amount of solar electricity consumed have been calculated as part of the study. It is often assumed that households consume around half of solar generated. In this study, on average, households consumed approximately one quarter to one third (24-32%) of the electricity generated by their PV panels. This is similar to other research findings in the UK[85]. However, monitoring showed households increased solar consumption over the study period, and Dwelling 4 increased solar consumed on-site from 29.5% to 38% indicating there is potential for further increase in on-site use of solar. Table C7 shows that if the proportion of solar on-site electricity consumed by the household is increased to 50 per cent of generation, the financial savings increase to around $2.32–$3.73 per day. If the proportion of solar on-site electricity consumed is increased to 50 per cent or more of generation AND the electricity imported from the grid is reduced by 20 per cent, then the benefit increases again so that 3 out of the 4 households would be in *net credit* over the period for electricity consumption (Table C8). The overall household electricity consumption is not reduced. Dwelling 6 is close to net credit for electricity consumed – but as this household has the highest import from the grid (601 kWh), in order to reduce costs they would need to further increase solar consumption and/or reduce electricity imported from the grid during the evening.

To illustrate the benefits of increased solar consumption, Table C9 shows that when households use 100% of solar generated, and import only 25 per cent of their electricity from the grid, they all have net credit of between $112.71 and $248.48, which works out between $2.01 and $4.44 per day. The overall household electricity consumption is not reduced. However, 100 per cent use of solar generated electricity is perhaps over-optimistic in practice. It should be noted that the financial benefits are likely to vary seasonally/annually, and be higher in summer when the solar generation is at its peak but negative in winter when the solar insolation is much lower.

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[83] Email communication with Russell Gerlach, PowerCor dated 19 October 2018.
[84] MyPower online platform, PowerCor 4 June 2019. Dwelling 3 received credit for solar feed in from 19/11/2018; Dwelling 4 from 13/06/2018; and Dwelling 6 from 12/03/2019.
[85] Clarke (2014); O'Flaherty & Pinder (2011).

The disadvantages of not using solar on-site are illustrated in Table C9: if households export all solar electricity generated and all electricity demands are supplied by the grid, then there is some financial benefit gained from feeding in electricity to the grid but a *net deficit* for all households ranging from -$175.56 for Dwelling 8 which is the lowest consuming household, to -$238.87 for Dwelling 3 (Table C9). This demonstrates the financial benefits of using solar electricity generated on site, and not exporting to the grid at current FiTs (at 9.9c - 13.5 c/kWh).

It is also evident from this analysis that the Service to property charge (daily charge) forms a significant proportion (accounting for between 26-50 per cent) of the households' electricity bill and therefore contributes to energy poverty for low-income households[86]. Even where grid consumption decreases in a household, the supply charge will remain the same – and therefore becomes a larger component of electricity costs for low consuming households. The calculations of costs and benefits in Tables C6-9 do not include the meter reconfiguration fee for conversation to solar. This is an additional cost for households installing solar PV, and varies between distributors and retailers depending on the works required.

Changing households' relationship with electricity

Becoming producers of solar electricity and generating a source of income

Evidence from this and other research suggests that producing solar power can change how households think about and engage with energy. In the UK research conducted with 31 solar PV owner-occupier households, found that the Government's feed- in-tariffs were highly significant in how households engaged with solar power. For example, some households kept detailed records of how much energy they were generating so they could work out the revenues they would receive. Similar to the households in this study, the flows of finance generated were understood in relation to household economies and future plans[87]. Whilst interest in the installation itself was not a key feature of the interviews with our participants, selling electricity back to the grid, where it contributed to managing

[86] The Independent Review of Gas and Electricity Markets in Victoria (August 2017) noted that the daily service to property charge or daily supply charge had increased as a component of bills. In line with the increases in fixed charges as a component of energy bills the Victorian Service to Property concession, which supports low energy consumption households, has increased significantly, from 2.6 million in 2005 to 14.5 million in 2015/16.
https://www.energy.vic.gov.au/__data/assets/pdf_file/0026/79172/FINAL-Report-2.pdf

Australian Energy Regulator Annual report (2018) on compliance and performance of the retail energy market 2017-18 released December 2018
https://www.aer.gov.au/system/files/Annual%20Report%20on%20Compliance%20and%20Performance%20of%20the%20Retail%20Energy%20Market%202017-18_0.pdf

The ACCC Retail Pricing Inquiry (2018) report recommends that concessions include a fixed dollar amount for daily supply charges and a percentage off usage charges, to ensure high and low usage customers are not disadvantaged, and concessions targeted at those who need the most assistance.

[87] Bulkeley et al (2014).

the household economy, appeared to be important for this cohort of female-headed households.

Financial benefit of a solar PV system, in terms of lower energy bills, is key consideration for low-income households living in social housing. The findings of our study align with previous research in the UK exploring the role that micro-generation technologies can play in alleviating energy poverty, which concluded that access to solar power can help reduce the proportion of household income spent on energy costs and help buffer against future rises in energy prices[88]. Similarly, another UK study of solar PV households living in an inner city and a rural village who were in energy poverty, found a reduction in energy bills by around one third[89].

Whilst analysis of electricity bills before and after PV installation reveals PV can be effective in reducing bills and contribute towards alleviating energy poverty, there is considerable variation in benefits between households. A study of 42 UK households in energy poverty also identified a considerable variation in bill reduction, and some households made no savings (i.e. bills increased after PV installation)[90]. It concluded that that greater attention is needed on supporting tenants to maximise savings through behaviour change, as well as providing monitoring technology and evaluation. The findings of these other studies can be helpful in exploring the complex reasons underlying behaviours and human/technology interactions, however, outcomes have to be viewed in context: benefits cannot be directly compared with Australia as installation costs, feed-in tariffs, fees and charges, solar insolation and generation are likely to be different. Cost-effectiveness is dependent on feed-in tariff rates, PV system size and performance, and on the proportion of PV generated electricity that is used on-site by residents.

Increasing engagement with electricity

As well as enabling electricity production, this study shows that PV offers the potential for households to increase energy engagement, even amongst initially 'non-active' consumers. From the initial interviews, the indication is that some participants are more *passive* – the expectation being that the PV would meet their electricity needs without active engagement. However, during the study most households demonstrated that they were capable of engaging with the technology, in some cases realising energy savings and becoming increasingly aware of their energy consumption and general electricity use, confirming findings from previous studies[91].

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[88] See O'Flaherty and Pinder (2011).
[89] Saunders et al (2012).
[90] Clarke (2014).
[91] Abi-Ghanem & Haggett(2011); Dobbyn and Thomas(2005); O'Flaherty & Pinder (2011).

The role of information and in particular, the ways in which information is provided is relevant to how households engage is highlighted in previous studies[92]. During the installation of PV in the domestic realm, attention should be paid to the ways in which users can engage with the technologies. In this case, participants were engaged through a visit by a home energy assessor, guidance from the research team, and using the MySolar app. However, to increase use of solar electricity on-site, tenants need additional support including information on how they might change their household routines to maximize the use of solar power (through clear documentation, home visits, etc.), as well as one-on-one coaching to navigate the MySolar app interface, and interpret the feedback.

The study has revealed the different ways in which tenants engage with PV technologies in their home. Passive consumers do not actively engage with the technology and there is little/no evidence of change in patterns of behaviour. Some participants have become more conscious of how they use energy, which suggests that living with solar PV encourages greater understanding and awareness around energy, which can have an impact on their behaviours. With guidance, some participants have modified their electricity consumption practices over time to use more solar power during the day to maximize benefits:

> *I'm using power more in the day because of what you've said about the solar and making that change of habit. So I'm giving it more attention now definitely. (Abby)*

> *Before solar I used to do everything – every evening, any time I want, but now there is some change, yeah.* (Aisha)

However, there is a need to increase energy literacy levels to inform occupants and assist them to use more solar power:

> *Just so I can clarify: So, when there is a peak of, say, 1.25 kilowatts, if I put on two machines – ... So, it would be better to put one on at 11 and one on at 12? (Abby)*

Others may use their solar power to justify higher electrical consumption, and see solar power as a way of increasing or maintaining consumption levels without an increase in the energy bill[93]. For some occupants, an increase in consumption is related to their requirements for convenience and comfort:

> *It [home energy assessment] was really good. I thought that [reverse cycle] was costing an absolute fortune to run, and I'm like, "I don't want to put it on." And, he said, "That's all right. It doesn't cost that much." And, he told me how much, and I went, "Oh! All right. We can just use it."* (Aimee)

[92] Clarke (2014); Abi-Ghanem & Haggett, (2011: 163).
[93] Abi-Ghanhem & Haggett (2011) and Ellsworth-Krebs and Reid (2016) highlight an *opportunistic* mode of use which occurs in the context of maximizing comfort or convenience while benefiting from the technology.

And, he [home energy assessor] told me that the biggest cost was the [electric] water heater. And then, I was just, like, "Oh, well. I like showers." At least I know. But, yeah. That's something that I choose, then, to use. (Aimee)

Reported behaviours from tenants are not always in the interest of reducing electricity bills. Sometimes participants reported load shifting for different reasons, depending on the situation that they found themselves in, and the needs they had to satisfy in terms of running a home with children or a large family, as in the following examples:

I use it [washing machine] at the daytime. Sometime if I forgot to wash the clothes for their school I do it at the night. … But I told them last week you have to think about your school uniform, tell me, if you come from the school three o'clock the sun is up, you tell me straightaway, get your clothes and put them to the washing and just put the machine on. (Bina)

I try to put that [tumble dryer] on in the day. Sometimes it has to go on in the evening if there's been an emergency wash, but generally it's on in the day now. (Abby)

…for washing machine it's hard to reduce because my son, he go to kinder four days. So, four days he wears different clothes, childcare yeah, you know. And night time they wear different. So to be honest, I wash all day, bed sheets Saturday Sunday, all their uniforms, my clothes, their clothes, the girl's clothes they wash too.. So, it's really busy – water and the washing machine, Saturday busy. (Ursula)

We have a small dryer but I use it only to dry the kids' clothes when the weather is no good. (Sera)

The following section discusses the challenges of managing household electricity production and consumption to maximize solar power, and how this intersects with flexibility – or the ability to shift household behaviours and routines.

Changing household behaviours and routines

As indicated by the load profiles in Appendix E, electricity consumption is closely related to household routines and activities within the home, including meal preparation and cooking, laundry, entertainment. Typically, there is a high electrical demand in the morning at breakfast time and a peak in the late afternoon/early evening when children return from school and dinnertime through the evening. Clearly this will be out of phase with, for example, generation from a north facing PV array. The consumption (load) profiles vary between the households in this study – with some having more electricity demand in the evening, and demand extending into the early hours of the morning. A variety of factors serve to modify this load profile and these include: number of household occupants, age, gender, time of the year, occupation patterns, income, and weather profile.[94]

In initial interviews, prior to installation of PV, participants were asked about their household routines and habits, which are often organised around structured activity, such as school times, in-between other routine/daily tasks or other activities:

> *I have class in Monday and Tuesday and Thursday, so just Wednesday and Friday from the morning until three o'clock – I pick up the kids and then we come back home. … So, on the other days … we come home from 3.30 or sometime 4pm. (Aisha)*

> *[Interviewer: And how often do you use the washing machine?*
> *Tenant: Every Saturday.*
> *[Interviewer: Every Saturday – so once a week?]*
> *Tenant: Yes, once a week. Yes, in all one day. Yes, I start from nine o'clock in the morning until 12 I finish. (Aisha)*

> *Tenant: I use it [washing machine] twice a week.*
> *[Interviewer: So you have a set rule that you use it like certain days ..?]*
> *Tenant: Yeah, we use it Friday and Saturday. …maybe two or three time.*
> *[Interviewer: … and when's the best time you like to do the washing?]*
> *Tenant: Afternoon. (Sera)*

> *[Interviewer: So, you normally run that [dishwasher] overnight, do you?]*
> *Tenant: No. Whenever I remember. Pretty lazy. Haven't got a routine set, of any sort. Whenever it's full, that's when it goes on. And, I overload it, too. So, no half-goes of that, either.* (Aimee)

Whilst most had routines for household tasks such as cooking, and doing the laundry, one tenant reported not liking set routines:

> *…you can't lock me into any kind of routine for anything, sorry, because I'm just not … – I do different things all the time.* (Aimee)

However, most communicated that they would be willing to change their routines and timing of some activities. During interviews, some tenants indicated more energy awareness and reported some changes in their routines since the getting PV, for example:

> *And the washing machine, I use it three times a week that the problem, because the kids are too much. But I use it at the day time. Sometime if I forgot to wash the clothes for their school I do it at the night. … But I told them last week you have to*

[94] Bahaj & James (2007).

think about your school uniform, tell me, if you come from the school three o'clock the sun is up, you tell me straightaway, get your clothes and put them to the washing and just put the machine on. (Bina)

I try and run the dishwasher in the day now or late morning instead of putting it on at night before I go to bed. Same with washing. Vacuuming I always do when it needs to be done, that's not something that can really change. (Abby)

Before I washed during the night time but now I do it at day time. Before I used to do it at 10pm and it would take more than one hour to finish. If I do two loads then it's longer, so very late. (Grace)

Nevertheless, the timing of some activities cannot be changed for institutional, social or other reasons, such as tiredness, as indicated by the example below:

[Interviewer: So, is that [cooking] something that you might be able to do – cooking when the sun's out, because you have an electric cooker?]
Tenant: Probably not. I can't study at night. Like, when the kids come home, that's the end of it, for me. When they're in bed, I'm just too tired. So, I probably wouldn't, because I like to try and – if I'm home, I like to be studying. (Aimee)

Cultural beliefs and practices affect the timing and frequency of many activities that use energy in households such as cooking and eating as part of religious observance:

I cook – like when it's Ramadan time, I cook every day. (Ursula)

Some everyday activities such as timing of children's meals are 'non-negotiable' because these services cannot be moved to another time of day for welfare or other valid reasons. However, research in the UK[95] has demonstrated that there is 'flexibility' in *how* a particular service is delivered e.g. serving food that is pre-cooked earlier in the day (mid-day/afternoon) or cooking food on a barbeque outdoors to reduce electricity used for cooking in the evening. On very hot days, living areas can be pre-cooled by turning on the air conditioner during the daytime. 'Negotiable' practices such as doing laundry can be moved depending on the weather and other considerations, which may involve altering weekly and daily routines, and perhaps setting a timer for using the washing machine, running the dishwashing or doing ironing in the middle of the day, to reduce electricity imported from the grid in the evening/night.

Analysis of electricity consumption load profiles confirms that some activities are being shifted into the daytime, to optimise self-generated electricity production, however, the peak demand is late afternoon to evening – particularly evident during hot summer days (Appendix E). Also, it is anticipated that electricity consumption will increase in winter – given that some households' main source (or

[95] Bulkley et al (2014); Fox (2016).

only source) of heating in winter is a reverse cycle electric unit, then the electricity consumption (imported from the grid) will increase early morning and evening, with heightened risk of increased costs and bill shock.

Improving load alignment
The most effective way of reducing electricity expenditure is to reduce import of electricity from the grid and therefore obtain the maximum value for the on-site electrical generation to benefit the householder as indicated in section 5.8 this is achieved by being flexible and changing activities to align consumption with solar production. The analysis shows that there is evidence of limited load shifting, as indicated in the load profiles (Appendix E). Providing guidance to assist occupiers adjust household routines and practices may achieve better load alignment, for example, recommending the use of high electrical demand appliances such as air conditioners, dishwashers, tumble dryers or washing machines at the peak of the solar day; and reducing baseload levels through more efficient domestic refrigeration and lower standby power consumption of consumer electronics. However, load alignment is not always straightforward for households to achieve due to social or cultural reasons, or other considerations, as previously discussed. Other technological solutions, such as combining PV with battery storage or communal battery storage, to reduce import of grid electricity at times of high demand.

Value of monitoring and feedback displays
Prior to installation of monitoring and the mySolar app the households received little feedback on consumption and savings. Households rely on billing, even though they were all connected to the internet and had smart phones and other devices, and electricity data is accessible through distributors web portals. This may be because the data is not 'live' and therefore of limited usefulness, or difficulties in interpreting information. One participant checked usage and cost frequently on the Powershop mobile app to help with managing the household economy. During interviews, all participants expressed an interest in having visual feedback from PV on their smart device (enabled through the Solar Analytics solar monitor).

While there are few if any other published Australian studies of mobile solar apps to compare, evidence from previous studies suggests that 'live' energy feedback displays can provide a variety of benefits. A study in South Australia offers insight into the interaction of residents with in-home energy feedback displays (IHDs) with solar PV systems: Lochiel Park Estate households (10) in South Australia most often used feedback displays for checking electricity usage, electricity generation from the solar photovoltaic system, the monitored data was also used for fault identification or system underperformance. The majority of households valued having live energy use and electricity generation monitoring in their home, although feedback data was used to maximize their economic return from the local solar feed-in tariff, by reducing electricity use during photovoltaic generation hours and maximising export to the grid when electricity is at its highest value[96]. In contrast to the South Australia case study, the tenant households in our study were provided with monitoring to manage on-site solar consumption. Similar to the South Australian study, our research found that in-home energy feedback displays can play a useful role in supporting and encouraging energy use behaviour change, and fault identification. Under-performing and malfunctioning PV technologies will result in a reduction in income for social housing tenants and undermine the economics of schemes for providers. A comparable 2016 UK study of low-income households with PV found that monitoring was instrumental in helping to develop and embed solar PV production and consumption knowledge in day to day routines[97]. However, it should be noted that even if feedback succeeds in increasing knowledge and awareness of energy use, this may not necessarily translate into behavioural changes, where energy use is perceived as non-negotiable[98].

Wider benefits

For the low-income households in this study, the principal attraction of having solar PV is the opportunity to save money on electricity bills. As Table C5 in the Appendix C shows, all households were able to save money on their electricity bill. Even if households are not currently making the most of their solar energy, they are, arguably, better placed to cope with potential future increases to electricity prices[99]. It is also an opportunity for households to change their relationship with energy and actively manage their consumption for increased financial benefit.

Amongst the other benefits of PV observed in this study and which are consistent with previous research: greater consumer engagement including greater energy awareness, increased use of solar power potentially leading to lower energy demand from the grid, and greater reliability of the electricity network.

Other outcomes relate to public acceptance of alternative ways of delivering energy needs; diversifying the energy mix; enabling broad participation of individuals and communities, as well as energy professionals, improving microgeneration technology targets to meet government targets in transition to a low carbon economy

6. Themes emerging from the study

This section summarises the key themes that emerged from the study. Themes highlight the commonalities between household experiences and illustrate the challenges for low-income households in managing energy and other household demands, and integrating PV into everyday routines. These themes may assist the housing provider, energy distributors and retailers, installers and regulators, in developing policy and programs to understand the layers of complexity in people's lives that contribute to barriers in take-up and integration, and to develop strategies

[96] Whaley et al (2013).
[97] See Fox (2016).
[98] Buchanan, Russo, & Anderson(2015); Hargreaves, Nye, & Burgess (2013).[98] Newbery & Green (2011 p.xxv)..

to assist in securing access to more affordable electricity (through renewables) and energy efficient homes.

6.1. *Housing inefficiency contributes to energy affordability problems*

Most of the tenants interviewed indicated that they were satisfied with the housing provided, and the accommodation met their current needs. However, some tenants may have felt their housing choices were limited, given their circumstances. All had been living in their houses for less than 2 years, with one participant having been in 11 different temporary accommodations in 9 months prior to settling in their current house. Whilst several considered retrofitting to make the house more energy efficient or comfortable, they had little or no capacity to make energy efficiency improvements to their homes due to limited income, affordability and complexity/lack of knowledge.

As indicated by the housing energy audits, dwellings varied in age and energy efficiency, but six dwellings had a low envelope Scorecard rating (1-2) and all were difficult to keep cool (Section 2.6). All of the tenants are living on a low-income and most were unable to spend money on improvements such as energy efficient appliances. As households vulnerability to health, wellbeing and financial impacts from rising energy prices is related to access to energy efficient housing and appliances, improving the energy efficiency of the building envelope which account for the largest energy use, will reduce heating and cooling loads and vulnerability to bill shock. Gradually replacing appliances with more energy efficient ones will also reduce household electricity consumption. In turn, if the housing provider is able to implement a program of measures this will enable households to improve comfort levels without increasing costs and household debt.

6.2. *Solar PV increases options available to households vulnerable to financial shocks to manage electricity consumption*

The findings of this study indicate that solar PV increases options available to low-income households to manage electricity consumption. As most of the participants in this study are at home for periods during the daytime, they are able to take advantage of self-generated solar to reduce electricity bills.

Whilst PV opens up new opportunities for low-income households to reduce the electricity bill, the direct and indirect financial benefits are offset against set-up costs for installation. Charges for PV installation (grid connected) include the cost of the equipment and installation, the safety inspection, and meter configuration (no details of fee provided). The tenant is responsible for paying the meter configuration fee. The meter configuration fee and increasing fixed supply or network charges (determined by the Distributor), combined with reduced solar tariff (Retailer/minimum set by State government in Victoria) counteracts benefits from solar (See Appendix C). As 'late adopters', participant households receive a Feed in Tariff of 9.9-11.3c/kWh. This is relatively low compared to the premium tariffs (20-60c/kWh) for early adopters. Also, there has been a steady increase in fixed daily supply charge and can be a high proportion of the electricity bill – depending on consumption. This makes it difficult for households to reduce overall bills.

Alternative business models may be required to enable households and cooperatives to engage with the energy market (not within the scope of this research).

It is evident from this study and previous research on households with solar PV, the key to success in reducing electricity bills is through active participation and using solar electricity as it is being generated on site. Analysis of households' daily load profiles reveals that modifying routines and practices can reduce import of grid electricity. By managing electricity consumption this means that households can look at ways of using solar credit to pay off energy-related debt or trading excess solar generated electricity, perhaps in conjunction with the community housing provider, wider cooperative community or another service provider.

Access to affordable energy services such as heating, cooling, cooking, hot water, requires not only time investment, but also available knowledge, skills, understandings and material arrangements. To reduce energy poverty requires a combination of energy efficiency (of systems, buildings and/or technologies) and improving households' capability, which will depend on household size, specific individuals' needs and circumstances e.g. age, disability, or special needs – and on the local environment, e.g. climate which is particularly significant for key energy services such as heating and cooling.

6.3. Householder – retailer relations: householders' experience leads to reluctance to engage with the energy market

Participants are from low socio-economic status (SES) households, all are sole parent families, are contending with multiple personal and family difficulties such as relationship breakdown and family violence, and managing health conditions. As sole parents the women are currently responsible for the care of children, often estranged from family and without assistance from another adult. This limits their capacity to spend time engaging with the energy market. This was outside the experience of a number of the participants.

For most participants in this study energy literacy is low, and for some, interaction with energy retailers adds a further layer of stress. During interviews participants related how moving to a new house and transferring to a new energy provider led to complexity in energy billing and energy usage. In one instance the wrong meter number led to a tenant being billed incorrectly; and in another instance when moving to a new house the tenant received bills for usage by a previous tenant; and a mix up between the two energy providers led to the participant being billed by both, which caused stress due to payment demands for arrears. Seven of the eight households are from migrant backgrounds and for whose first language is not English, this seemed to be a hurdle in resolving such issues over the telephone, or incorrect understanding of letters from distributors and/or retailers. During the study one participant requested assistance from the researcher as she did not understand the written communication from the retailer about the meter reconfiguration charge for connection of PV. Most of the participants expressed a mistrust of retailers, being 'let down', and a perception that energy companies are not acting in their interests e.g. being charged more for being on a payment plan. All of the above add further complexity in making efforts to improve energy literacy and engagement.

6.4. Technology and energy literacy combined with tailored support offer pathways to improving engagement, capability and reducing energy poverty

Although PV is well-suited to community housing because of typically high daytime occupancy rates, benefits are limited if tenants do not understand or adapt their electricity use to maximise savings. This is not specific to this study but appears to be a widespread issue. In this respect, landlords need to provide more effective guidance to the tenants and support them to make behaviour changes.

Tenants involved in this research demonstrated low levels of energy literacy, and a lack of understanding about the PV system. For example, most interviewees did not know what their current tariff was; some did not realise that using appliances during the daytime would help maximise their savings from PV; few appreciated the requirement not to use appliances simultaneously. There is need for more intensive and interactive support when providing energy feedback, for example, face to face communication with installers or trusted third parties, and clear guidance for tenants to get the most from PV.

6.5. Energy-related debt is an increasing problem for low-income households and impacts on ability to choose the best energy deal

The literature shows that energy-related debt and disconnections are a key issue for a growing number of households[100] which suggests that existing measures are not effective and alternative strategies are required to address energy hardship. All participants are sole parent households on low-incomes and are likely to have little income or wealth to buffer against the negative impacts of large energy bills, or an adverse health event. Regular household bills (including electricity, gas, water, rent, internet and mobile telephone) have to be budgeted from one limited income. The findings from this study align with previous research on behalf of Victorian Council of Social Service (VCOSS) and a survey by the Public Interest Advocacy Centre (PIAC) which found that consumers go to various lengths to avoid disconnection, including cutting back on buying food or other groceries, seeking one-off assistance, borrowing money from family members, and delaying medical treatment. Participants' reported experiencing ongoing stress and/or anxiety associated with paying their utility bills alongside other regular and unpredictable expenses. Most participants are currently or have previously been on payment plans.

Energy-related debt is an increasing problem for low-income households and impacts on ability to choose the best energy deal. As indicated previously in section 4 of this report, households with energy-related debt and poor credit rating can find it difficult to access the best energy deals, limiting the options available. However, it is in households' and energy retailers' interests to ensure households have the best

[100] Australian Energy Regulator 2017; Essential Services Commission 2017;
See also ABC Power Special Part 1: 25 March 2019 https://www.abc.net.au/news/2019-03-25/power-special:-part-1/10938042?section=business

deal. Managing electricity bills and remaining out of energy debt will improve the lives of these households significantly while also reducing retailer costs associated with bad debt[101]. Although two households did switch providers during the study, there is no assurance that low-income households are getting the best energy deal for them. Households with low levels of literacy/numeracy would benefit from one-on-one assistance by a trusted third party on selecting the best import–export tariff regime for their needs and how to avoid export of electricity to maximise financial return.

6.6. *PV industry is still maturing and not accustomed to engaging with the community rental sector – need to develop reliable procedures for installation, operation and maintenance*

This study has identified systemic failures in PV installation and connection between the installer/electrician, distributor and retailers to submit and/or process the necessary meter alteration request, or expiry of pre-approval. This resulted in long delays in meter reconfiguration after installation of PV – during which time households did not receive credit for feed-in of excess solar to the grid, leading to tenant frustration and loss of financial benefit (although households were able to use solar generated on site). This appears to be due to a number of reasons including: failure of the installer/electrician to submit a meter alteration request; the various different stakeholders involved in the re-configuration, and accountability for the various steps; uncertainty around whether the distributor, system owner or the tenant is responsible for oversight of that process. This could have been avoided if responsibilities for follow up by the system owner had been made clear, and with better oversight through earlier intervention by the distributor and housing provider.

6.7. *Limitations on access to household electricity data prevents learning and capability*

Household electricity consumption data currently available to domestic customers is not real time and this feedback is of limited value to households seeking to optimise use of solar electricity.

Gathering energy consumption data from energy distributors was very challenging: energy suppliers do not have adequate processes to provide such data and in other cases, sufficient historic data does not exist due to changes in tenancy. Despite providing written permission from participant households, and repeated requests for historic household data, this study identified issues with accessing household electricity consumption data via the energy distributor (Jemena). It is vital that procedures for third party access to household electricity data are standardised and simplified to enable energy consumption data to be collected more easily and quickly.

As noted by the recent ACCC inquiry report, greater access to their electricity usage data represents an important opportunity to empower consumers. While some

[101] ACCC (2018).

consumers may not have the level of literacy to analyse detailed electricity production and consumption data, the application of the Consumer Data Right to the electricity sector will hopefully see opportunities for electricity usage data to be made available to consumers and, importantly, agents of consumers where consent is provided: this will enable innovation by third parties providing services to consumers in finding the best electricity offer.

7. Conclusions and recommendations

This small but in-depth study has followed the installation of solar PV in low-income households living in community rental housing in Melbourne's western suburbs, to investigate the effectiveness of PV installations and energy performance feedback in managing energy consumption for housing tenants, and identify the social and financial benefits associated with integration of PV technologies for this cohort. The research addresses a gap in knowledge, as there is little evaluation of the effectiveness of distributed energy technologies to meet the needs of tenants and community housing providers.

This project provides detailed evidence on the low-income families' energy needs, practices and usage, and evaluates financial and other benefits derived from PV Installation. The research fills a gap in knowledge in end-users experiences and identifies several challenges to integration of solar PV in low-income and vulnerable households. The research makes a valuable contribution to informing the development of effective mechanisms to deliver renewable energy retrofitting and alleviate energy poverty, and achieving societal goals.

Whilst the primary aim of the study was to examine the feasibility of the technology to reduce energy poverty, the installation project also provides a learning opportunity for electricity suppliers, housing providers, installers and other key players in the area of design, construction and monitoring of photovoltaic installations and challenges in retrofitting renewable technologies in community rental housing. Knowledge from this pilot would benefit the those involved in deployment of this type of renewal energy technology in social housing. As such, the findings will be of interest to a range of stakeholders including community housing providers, the energy industry, consumer advocacy organisations, government policy makers and Regulators.

Taking an interdisciplinary social science approach to understand the user perspective, qualitative interviews with eight households, together with monitoring actual electricity use, the study has explored the challenges and benefits for low-income tenants. This study provides social and technical research evidence that solar PV can deliver modest financial benefit and other social outcomes for low-income rental households. The pilot research findings indicate that the main sources of financial benefit from the PV is the savings to household electricity bills i.e. by using the electricity the PV generates in the home at the time of generation, saving electricity purchased from the grid, and also exporting surplus electricity to the grid. The research also highlights the potential to use credit towards reducing energy-related debt.

In terms of social benefits, interviews with participants suggest that reducing financial stress and "bill shock" are very important to low-income households' wellbeing, and this study indicates that PV could have a positive impact on reducing stress and anxiety. Heating and cooling accounts for a high proportion of household energy costs for the family households in this study. Solar PV can assist in managing electricity for cooling during the afternoon when PV is generating, however, improving energy efficiency of the building envelope is critical in reducing heating and cooling loads, and improving occupant comfort throughout the year.

The study also identified a number of challenges and risks to alleviating energy poverty. The most effective way of reducing household electricity expenditure is to reduce import of electricity from the grid. Our analysis showed an increase in household electricity consumption following installation of PV, indicating a rebound effect ranging from 16 to 54 per cent. Three of the four households monitored also showed a slight average increase in electricity imported from the grid over the study period of between 2 and 5.4kWh per day. However, the analysis of load profiles shows that there is scope for grid consumption to be reduced with alterations to routines and when household appliances are used. Depending on funding availability, there may be opportunities for combining solar PV with batteries – however, this would need to be accompanied by an increase in learning and capability in operating the technology and energy literacy.

In terms of other benefits, the provision of solar PV contributes to government policy objectives for broadening energy participation to individuals and communities who may not otherwise be able to purchase solar PV due to financial and institutional constraints, and for addressing social inequalities. Amongst the wider benefits of PV are: greater consumer engagement including increased energy awareness, increased use of solar power potentially leading to lower energy demand from the grid, and greater reliability of the electricity network; public acceptance of alternative ways of delivering energy needs; and achievement of government objectives to diversify the energy mix.

Whilst this study provides detailed evidence to support the proposition that PV can contribute to reducing energy hardship and poverty, the benefits are highly dependent on households' ability to make use of the solar generated on site. The financial benefits of solar are limited by the meter reconfiguration fee, low Feed-in Tariffs for late adopters and retailers' high daily charges – the latter accounts for a high proportion of bills for low electricity consumers, typically households on low- and fixed-incomes. The evidence suggests that a multifaceted approach to energy poverty is required that involves a combination of energy efficiency (of systems, buildings and/or technologies) and changing behaviours through improving households' energy literacy and capability, and review of tariffs and reduced fees. The indications are that solar monitoring and visualization of solar production can assist in improving households' awareness and capability in managing consumption and production, and engaging with the electricity market, however, further research is necessary to determine how households are using the mobile app and the outcomes over a longer period.

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Appendix A: Participant demographic details
Appendix B: Interview questions
Appendix C: Electricity production and consumption
Appendix D: Temperature and humidity data
Appendix E: Selected electrical load profiles