Regional and Remote Communities Reliability Fund Microgrid

MyTown Microgrid

Load flexibility: will it work for Heyfield homes?

Heyfield local energy options: techno-economic analysis
Milestone 5.2b – May 2023

Research Team

Work Package Lead: Jay Rutovitz, UTS

Research team: Heather Smith, Dr. Soheil Mohseni, Dr. Rakib Shah (Federation University, Australia)

Chief Investigator: Dr. Scott Dwyer, UTS

Key support

Federation University Australia

Wattwatchers Digital Energy

AusNet Services

Heyfield Community Resource Centre

Latrobe Valley Authority

About the project

MyTown Microgrid is an innovative, multi-year, multi-stakeholder project that aims to undertake a detailed data-led microgrid feasibility for the town of Heyfield (Victoria), built on a platform of deep community engagement and capacity building.

The project received funding under the Australian Government's Regional and Remote Communities Reliability Fund Microgrids stage 1 funding round. It also received funding from the Latrobe Valley Authority as part of the Gippsland Smart Specialisation Strategy.

Citation

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Executive Summary

The MyTown Microgrid project is developing an innovative data-led approach to microgrids and local energy solutions, starting with the town of Heyfield in Victoria. Built on a platform of deep community engagement and capacity building, the project is also creating the knowledge and tools to make it faster, easier, and cheaper for other regional communities to understand the proposition for microgrids, and for complementary local energy solutions, for their towns.

This report describes the economic potential of residential load flexibility for Heyfield stakeholders, including solar and non-solar householders, energy retailers, the network business, and the supporting technologies for implementation. It summarises the findings obtained from modelling load shifting scenarios for key flexible loads. The findings will inform the analysis of the business case for a community battery, energy efficiency upgrades, and community retailer/aggregator models.

What is load flexibility and why is it important?

Load flexibility can help shift the time of energy use to when energy is plentiful (and therefore cheaper), shaping the patterns of demand to better match the availability of renewables. Residential loads with the potential for flexibility include electric water heaters of different types and air-conditioning for heating and cooling. Load flexibility has been increasingly recognised as a cost-effective resource for the integration of variable renewable energy sources. To illustrate, shifting demand using load flexibility can reduce costs and make more use of onsite solar photovoltaic (PV) generation and/or take advantage of lower rates during off-peak hours.

How did we evaluate the economics of residential load flexibility?

We adopted a data-led modelling approach building on Milestone 5.1, *Typical residential load profiles for Heyfield*. The load and sub-load profiles and household solar PV profiles were derived from a fleet of 107 household-level devices installed within a total of 96 houses in Heyfield (out of approximately 700 houses in the town)[1].

We then evaluated the potential for load flexibility to reduce customers' bills by developing control scenarios that model load shifting. We undertook the modelling using the energy planning software, Gridcognition.

We evaluated the most significant sources of load flexibility at typical individual sites, namely the heating, ventilation, and air-conditioning (heating, ventilation, and cooling, or HVAC) and various hot water systems, including standard resistive hot water, heat pump hot water, and electrically-boosted solar water heater (SWH) systems. All the analyses are carried out for customers with and without solar, and those who are currently on time-of-use and flat-rate tariffs. Where relevant, we distinguished the hot water systems that are currently on a controlled load tariff through a dedicated circuit.

We did not include electric ovens as potential flexible loads, as we judged shifting cooking from peak periods (3pm – 9pm) would be socially unacceptable. It would also potentially require different trade-offs for each individual, making it unacceptable for many.

We did not have load profiles for plug in appliances, such as washing machines and dish washers, as these are not monitored separately. Instead we have estimated potential savings from shifting usage to times of solar generation for customers with solar, and note that if customers switch from flat rate to time-of-use tariffs it will be important to keep usage out of peak times as far as possible.

Modelling results

Figure E1 shows the impact of load flexibility on annual electricity bills for households with and without solar. All households are assumed to have HVAC systems, and one of three different types of water heating (standard, heat pumps, or SWH with electric boost)[a]. We found that both households with and without solar

[a] Almost 1/3 of households in Heyfield use LPG to produce hot water. Any initiatives to replace LPG with electrical systems will result in the need to consider the flexibility of a new hot water system.

can benefit from implementing load flexibility, with savings of between $131 and $393 per year[b]. The greatest potential savings ($393 per year) were for non-solar customers with HVAC and uncontrolled standard resistive water heaters on flat-rate tariffs.

Flexing loads that are currently on controlled circuits with low tariffs (standard or heat pump water heaters) were only analysed for solar households, who could make savings by increasing the amount of self-consumption of solar generation. For non-solar customers, only uncontrolled water heating was considered, as flexing controlled loads would not produce savings because controlled load hot water is already on the lowest tariff available, and there is no option for self-generation.

We found that HVAC systems and standard resistive hot water systems are the most cost-effective sources of load flexibility at the domestic level, which supports the findings in the literature[2]. Flexing HVAC offered potential savings of between $83-$226 per year for solar customers, and $192 per year for non-solar customers. It should be noted that only homes with sufficient thermal mass to store daytime heating in the building fabric will be able to heat up before 3pm and then hold a comfortable temperature through until 9pm.

For customers with solar, flexing electric hot water systems that are currently uncontrolled saved between $65 (standard) and $103 (heat pump) per year, while flexing currently controlled electric hot water systems saved between $59 (standard) and $128 (heat pump) per year. It should be noted that for standard water heaters of customers with solar, an enabling cost of $1,425 was considered for solar diverters, while control of heat pump water heaters relied on their built-in timers. For customers without solar, flexing heat pump water heaters offered savings of $92 per year and standard hot water systems offered savings of $151 per year.

The savings generated from flexing the electric boost for solar water heater systems are less than the cost of enabling technologies. For solar households, the financial driver for increasing solar self-consumption is the difference between the feed-in tariff (FIT) offered for exports and the tariff charged for grid consumption[c]. The modelling presented here assumes a FIT of 5 cents/kWh and will not apply to those residents still on legacy premium FITs of (a minimum of) 60 cents/kWh; these are due to finish in November 2024.

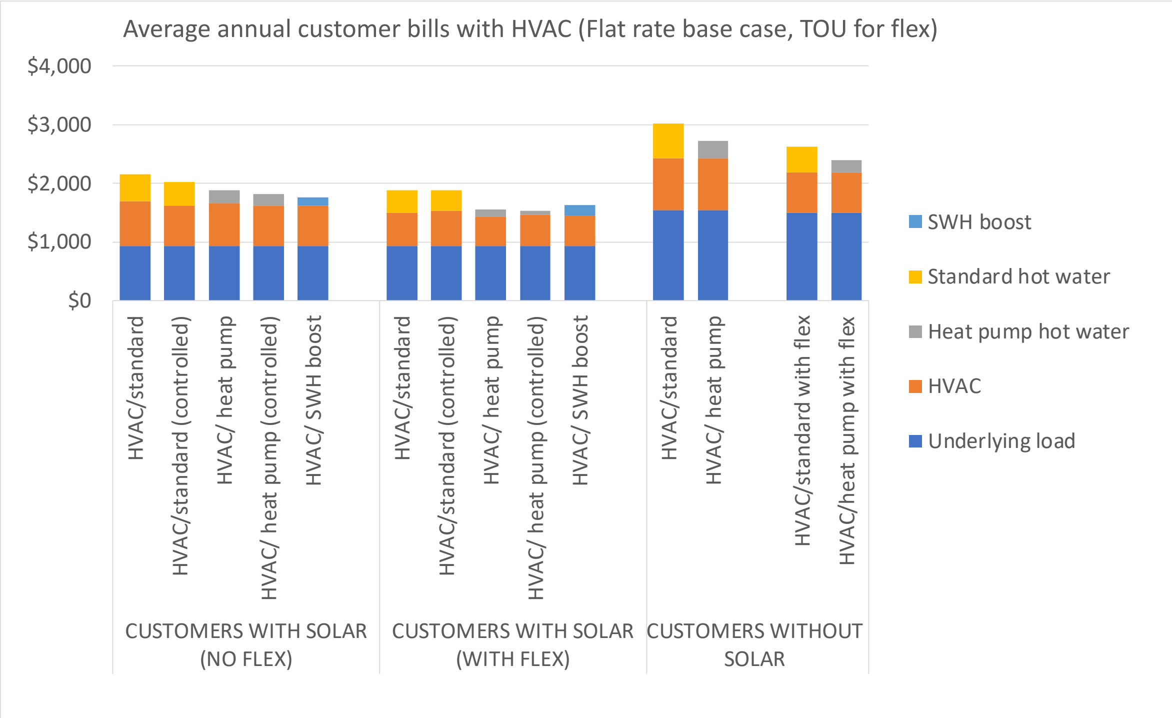

Figure E1 Overview of the impact of load flexibility on customer bills

[b] The annual bill shown is the 10 year cost divided by 10, and includes the cost of enabling technologies where relevant.
[c] When the FIT was 60c/kWh for solar exports, it made financial sense to export your solar and pay to import, as even at peak rates of 40c/kWh you are better off by 20c/kWh for each kWh exported. When the FIT is reduced to 5c/kWh and the cost of importing is about 30c/kwh (off-peak) or 40c/kWh (peak), people are better off by at least 25c/kWh from using their own solar rather than importing, even at off-peak rates of 30c/kWh.

Customers with solar panels who shift dishwasher or washing machine use to take advantage of self-generation could save on average $10-$30 per year (washing machines) and $30-$65 per year (dishwashers), depending on whether all or some of usage was met by the solar system. For customers without solar who shift from a flat tariff to a time-of-use tariff in order to benefit from load flexibility, ensuring these appliances are used in off-peak times could only save between $30-$65.

Figure E2 shows the analysis by stakeholder, including the total annual customer bill in each case (dark blue lines), the network charges, the retail margin, and an approximation of wholesale energy costs, and the technology cost associated with flexing the load. The retailer receives the entire electricity bill apart from the technology cost and is liable for the network and environmental charges and the energy costs.

Network charges are reduced by load flexibility, which indicates the network business will receive less revenue. However, in the longer run, this can help to defer or avoid capital-intensive network investments that would otherwise be necessary to meet the increased demand from EVs and other emerging technologies, as well as increased electrification interventions.

The retail margin is estimated by subtracting the modelled wholesale energy cost, network charges, environmental charges, and any costs attributable to the load flexibility enabling technologies (where appropriate), which are assumed to be incurred by the customers[d].The electricity retailer shares the gain from reduced network charges, with load flexibility expected to improve margins in serving both customers with and without solar. In one of the base case calculations (without flexibility) the retailer is shown losing money, as the customer bill is less than the network charges plus the environmental charges and wholesale energy costs, although in practice retailers are likely to pay lower energy costs than estimated from the wholesale market.

The results suggest thin margins for retailers without load flexibility. This is consistent with the findings of a recent report by the Australian Competition and Consumer Commission (ACCC), stating that average retail margins for residential customers across the National Electricity Market continued to decline in 2021–22 from their peak in 2016–17[3].

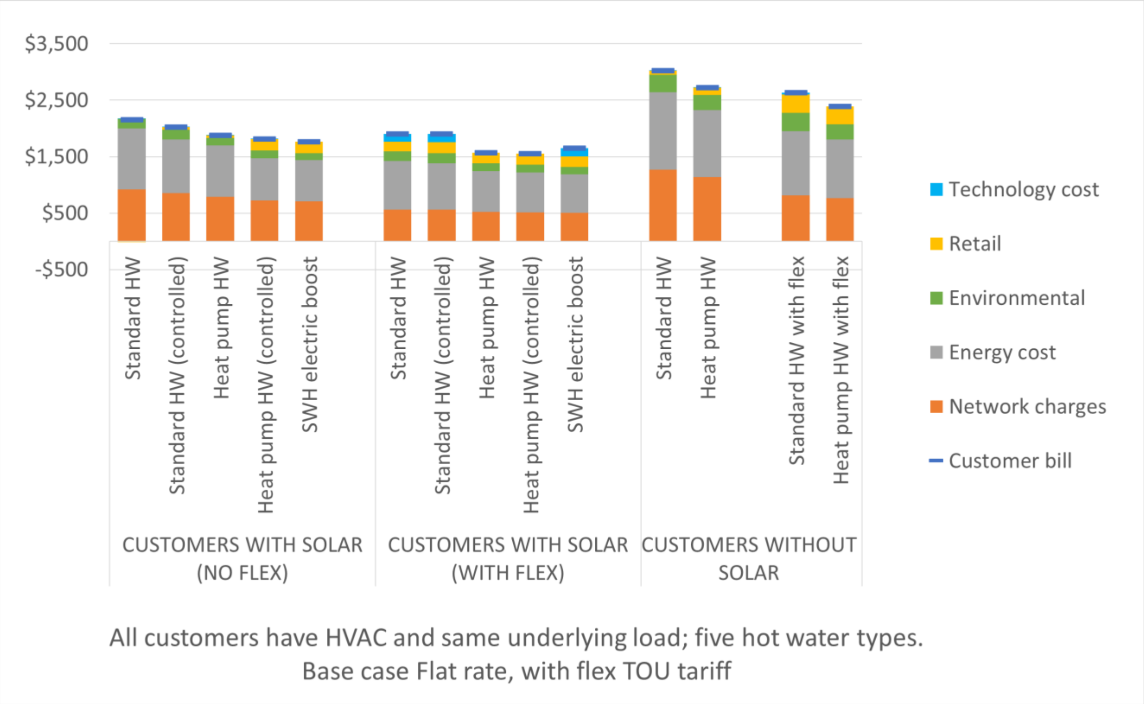

Figure E2 Analysis by stakeholder results (customers, network business, and retailer)

[d] The modelling software uses wholesale price profiles to estimate energy costs, although in reality retailers will have complex arrangements in place to purchase electricity, with only a small portion sourced on the wholesale market. The retail margin shown includes environmental and market costs.

Total potential load reduction

We also estimated the potential maximum peak load reduction using the available flexible load resources. In order to do so, we scaled up the household-level estimates of load reduction for HVAC and water heating to represent all the houses in Boundary 3 within Heyfield. The greatest potential for load shifting was found to come from HVAC, where loads of up to approximately 2 kW per household basis can be shifted to times when solar generation occurs.

A maximum potential load reduction of 600 kW was calculated for flexing HVAC during the summer peak, which could provide a significant resource for Heyfield, as the estimated peak load is 5,300 kW. The potential overall load reduction for water heating is much smaller, with a maximum of about 50 kW for standard resistive loads, and another 20 kW for heat pumps.

The community load for controlled water heating is much higher, with an estimated winter peak of 320 kW[e]. This load has not been included as it is already flexible. As more households install solar it becomes economically attractive to switch away from the current controlled tariffs, and it is important to build in the ability to follow the generation from the start to ensure it remains flexible.

Conclusion and recommendations

Based on the analyses and findings presented, implementing effective load flexibility strategies could reduce energy costs for some residents, increase the proportion of locally consumed solar, and reduce the town's peak load.

Both households with and without solar can benefit from load flexibility, with load shifting improving solar self-consumption for solar households. Estimates for potential savings vary from $59 (customers with solar and controlled standard hot water system, without HVAC) to $393 (customers without solar, with uncontrolled standard hot water systems and HVAC)[f]. Savings are dependent on current usage, in particular of HVAC systems.

The following set of recommendations are provided for *Heyfield MyTown Energy to consider:*

1. *Consider running a pilot load flexibility programme:* while this could be standalone, it is likely to produce better outcomes as part of a package of on-site measures.
2. *Prioritise load flexibility for HVAC systems where applicable:* as this is the main source of cost savings from flexibility. Note that this is only likely to be effective where there exists sufficient thermal mass to store daytime heating in the building fabric, flexing HVAC can be low cost, as it simply requires programming built-in timers to align with off-peak electricity tariffs.
3. *Consider combining with advice on fabric improvements:* the effectiveness of flexing HVAC is likely to improve if combined with improving energy efficiency with measures such as insulation and draught proofing (these also improve comfort).
4. *Consider the impact of load flexibility on thermal comfort:* shifting the load means you are pre-cooling or pre-heating the home, so people should consider how this will work in their circumstances.
5. *Evaluate the potential benefits and limitations of load flexibility strategies for each individual household:* this includes considering factors such as the availability of flexible resources, the level of solar generation if applicable, the current tariff, and current spending on HVAC, to determine the potential savings from load flexibility. We advise using a simple calculator to assess the benefits.
6. *Evaluate the impact of the end of premium feed-in tariffs on solar customers:* as of November 2024, the premium feed-in tariff rate will expire and be reduced from $0.60/kWh to $0.05/kWh. This will increase solar customers' bills considerably. Implementing load flexibility strategies to maximise the use of their own solar electricity is the most effective way to mitigate this.

[e] This load occurs during off peak times as it is controlled.
[f] Note that for standard water heaters of customers with solar, an enabling cost of $1,425 was considered for solar diverters, while no establishment cost was considered for heat pump hot water systems.

7. *Provide education and training to households:* on how to effectively implement load flexibility strategies and how to use the tools available to them, such as built-in timers and home energy management systems. This includes training on the different energy tariffs and how to understand electricity bills, how to program and adjust timers for HVAC, and how to monitor and track energy usage. Providing education and support will increase the likelihood of successful implementation and achieve the desired energy cost savings.
8. *Encourage the use of energy monitoring and management systems:* for example, Wattwatchers monitoring devices. Using these systems will make load flexibility strategies more effective, and help customers reduce overall energy use. Monitoring devices can provide households with detailed, real-time information about their energy usage, including the breakdown of usage by appliance. This could give households a better understanding of their energy usage and enable more informed decisions about load flexibility strategies and other measures, which can lead to greater energy cost savings.

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Abbreviation	Description
BDR	Behavioural Demand Response
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DLC	Direct Load Control
DNSP	Distribution Network Service Provider
DRED	Demand Response Enabling Device
EV	Electric Vehicle
FCAS	Frequency Control Ancillary Services
FiT	Feed-in Tariff
HEMS	Home Energy Management System
HVAC	Heating, Ventilation, and Air Conditioning
MEM	My Energy Marketplace
P2P	Peer to Peer
PV	Photovoltaic
PWM	Pulse Width Modulation
SWH	Solar Water Heater
ToU	Time of Use
VPP	Virtual Power Plant

1 Introduction

The Heyfield MyTown Microgrid project is undertaking a detailed data-led microgrid and energy solutions feasibility study for the town of Heyfield (Victoria), built on a platform of deep community engagement and capacity building. Over the three-year duration, the project will develop the knowledge and tools to make it faster, easier, and cheaper for other regional communities to understand microgrids and other energy solutions for their community.

The MyTown Microgrid project provides a range of reports and resources, including documenting Heyfield's journey to explore a microgrid and other local energy solutions[g].

1.1 What is load flexibility and why is it valuable?

In light of the ever-increasing penetration of non-dispatchable renewables (and hence, the challenge of balancing supply and demand), the implementation of effective load flexibility and interventions to control electricity consumption in real time are increasingly important. Load flexibility can help shift the time of energy use to when energy is plentiful (and therefore cheaper), shaping the patterns of demand to better match the availability of renewables. This includes managing electric heating loads such as heat pumps and electric resistance storage water heaters, as well as electric cooling loads to transfer heat out of buildings during the summertime. Load flexibility has been increasingly recognised as a cost-effective resource for the integration of variable renewable energy sources.

Making more use of onsite solar photovoltaic (PV) generation and flattening demand using load flexibility schemes can provide an effective means to avoid network charges and take advantage of lower rates during off-peak hours. Figure 1 illustrates how harnessing the flexibility potential of small- and medium-sized end-users can help to efficiently manage the electricity demand and contribute to flattening the net load profile – with consequent implications for improving system efficiency and better use of resources[4].

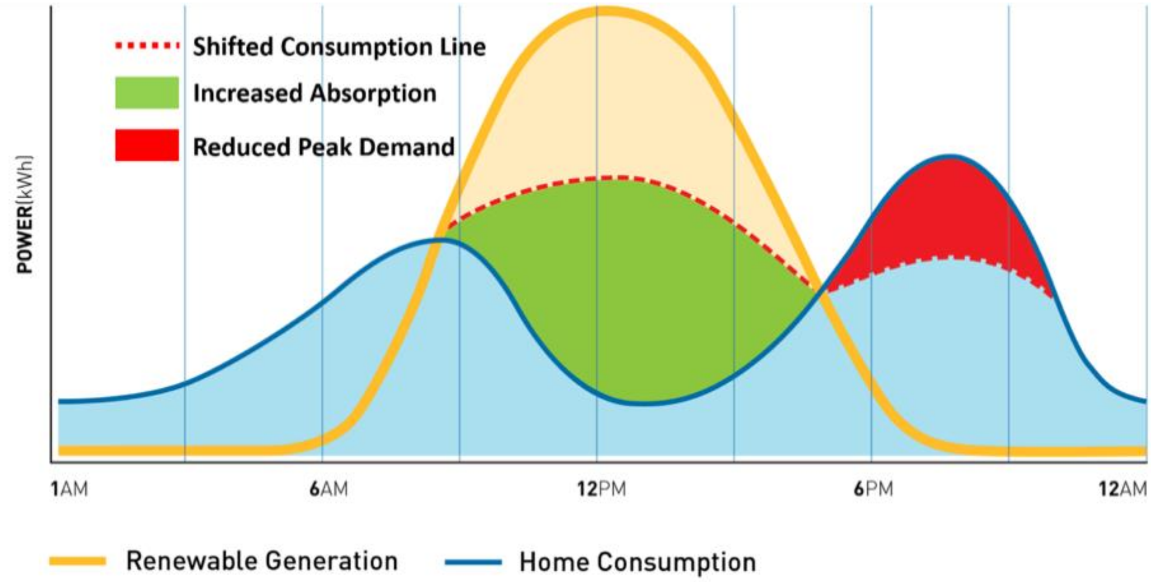

Figure 1 Illustration of the impact of load flexibility on supply-demand mismatches[5].

1.2 A data-led modelling approach

This report builds on Milestone 5.3a, Typical residential load profiles for Heyfield. The load and sub-load profiles, as well as household-level solar PV profiles used in this study, are derived from a fleet of 107 household-level devices installed as part of the MyTown Microgrid project and the Wattwatchers My Energy

[g] https://www.uts.edu.au/isf/explore-research/projects/mytown-microgrid-heyfield-victoria

Marketplace (MEM) project.[6] The devices are installed within a total of 96 houses[h] (out of approximately 700 houses in the town).[i]

1.3 Overall aim and objectives

The overall aim of this report is to evaluate the potential of load flexibility for Heyfield homes in reducing customers' bills by developing load flexibility and control scenarios that model load shifting. Specifically, to evaluate the economic value of load flexibility at typical individual sites, the flexibility potential for heating, ventilation, and air conditioning (HVAC) and various hot water systems are determined.

[h] Which can be broken down into 63 houses as part of the MyTown project and 33 houses as part of the MEM project.
[i] The number of devices, as well as premises and businesses, are effective as of June 2022.

2 Background

Load shifting demand response can provide significant benefits to customers in terms of reducing energy bills by allowing them to shift their electricity consumption to times when energy prices are lower, thereby maximising the economic efficiency of their energy use. In addition to economic benefits, load shifting demand response can also help to reduce strain on the electrical grid, particularly during periods of high demand, potentially improving overall grid stability and reliability.

This section provides an overview of the average consumption and solar PV generation profiles derived from a fleet of 107 household-level Wattwatchers devices. More specifically, the average hourly electricity consumption per season for different household types disaggregated into the major sub-loads of HVAC and electric water heaters, as well as everything else (that is, general power or plugs, including ovens), as well as the average hourly solar PV generation of a typical house per season, are provided.

2.1 HVAC sub-load

The HVAC sub-load profile has been derived from all dwellings with HVAC. Figure 2 shows the average hourly electricity consumption of the HVAC system of an average house per season. The numbers in the titles (n) are the total number of households used to derive the average load in each case. As one would expect, more electricity tends to be consumed by an average-sized HVAC system in both winter and summer, as compared to autumn and spring.

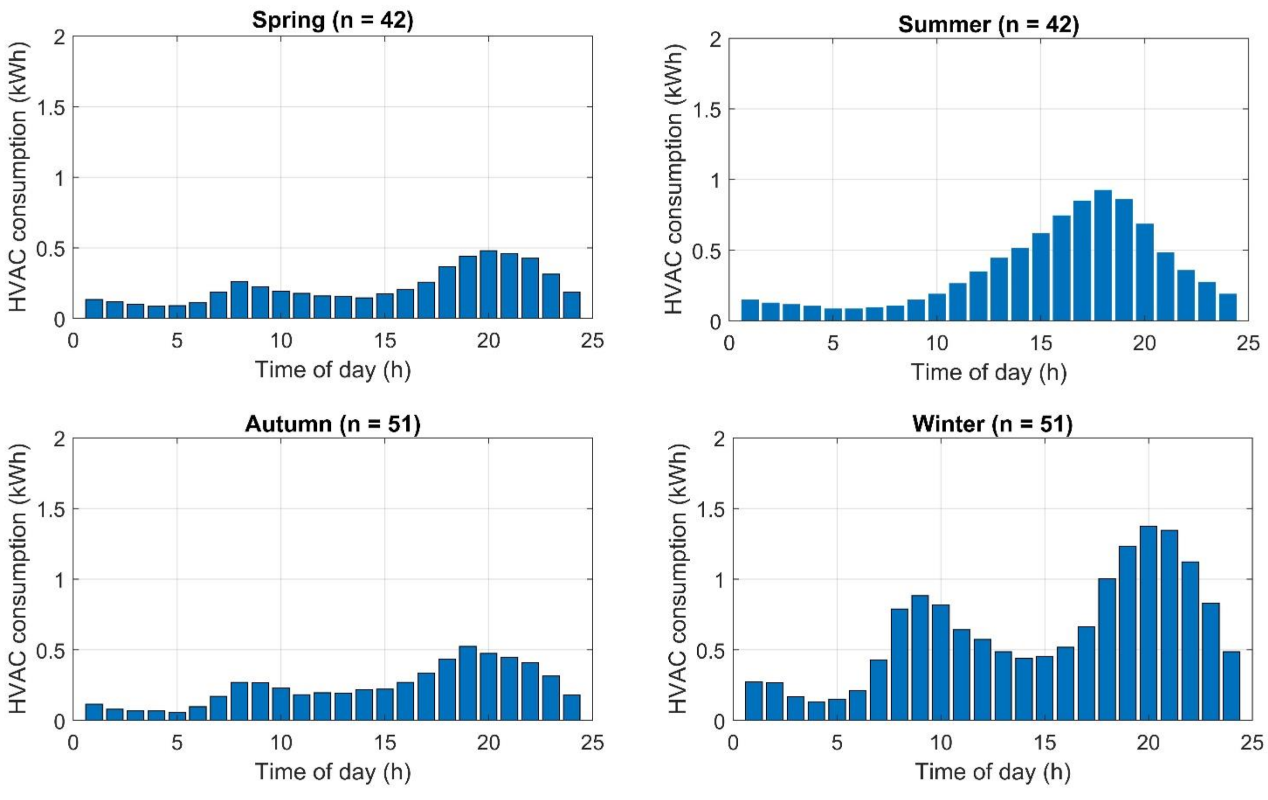

Figure 2 Average hourly electricity consumption per season, HVAC

2.2 Electric water heater sub-load

As described above, for the purposes of this study, the electric water heating systems are broadly classified into (i) standard electric hot water cylinders which include an electrical heating element, (ii) heat pumps, and (iii) electric boost for solar water heater (SWH) systems.

2.2.1 Electrically boosted solar hot water

Most of the electrically boosted SWH systems are on night-rate controlled load tariffs. Figure 3 displays the seasonal per-occupant average hourly electricity consumption profiles for electric boost elements of SWH systems that are connected to night-rate controlled load tariffs.

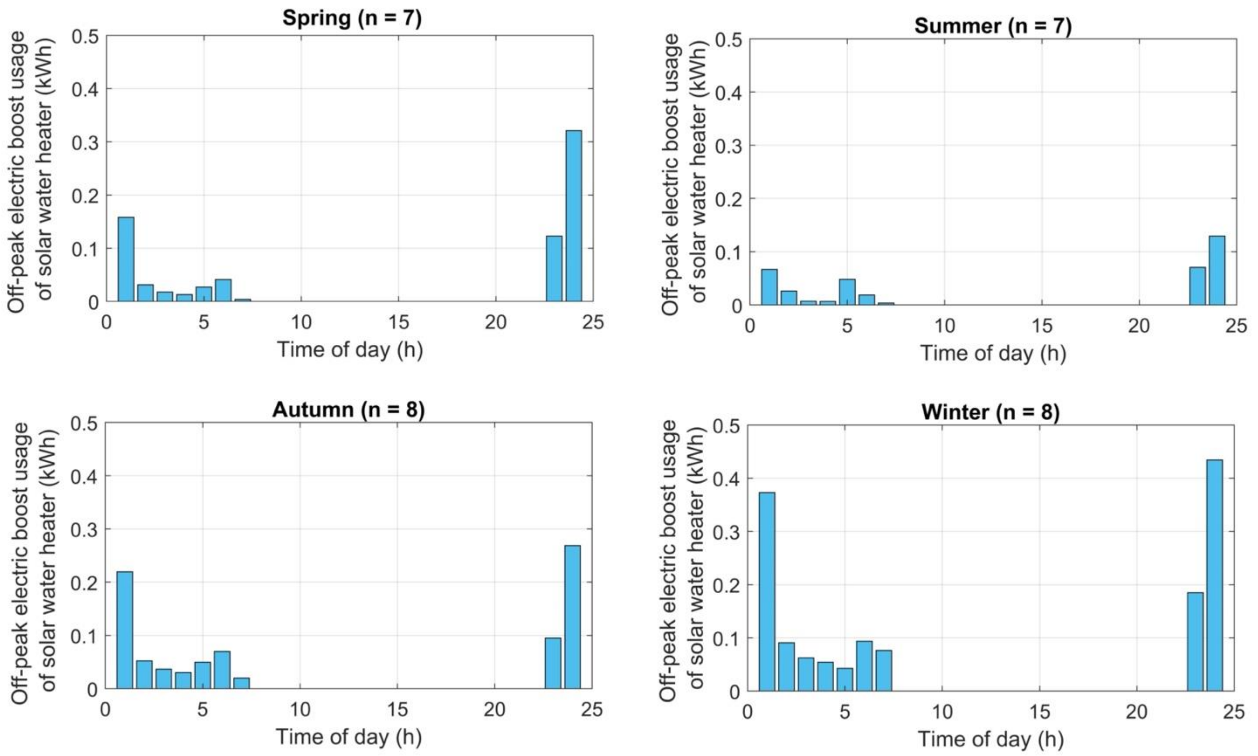

Figure 3 Average hourly electricity consumption per season, electric boost of SWH (controlled) (on a per-occupant basis)

2.2.2 Conventional resistive hot water systems

Figure 4 shows the seasonal average hourly electricity consumption profiles for standard electric element hot water systems on continuous electricity supply tariffs on a per-occupant basis. As the figure shows, autumn and winter constitute generally higher electricity consumption than spring and summer. The morning and evening peaks in winter portray up to 300 Wh per occupant on average. The morning and evening peaks in other seasons are similarly almost the same at about 200 Wh per occupant in spring and autumn, and 150 Wh per occupant in summer.

Figure 5 depicts the derived seasonal average hourly sub-load profiles for the standard electric element water heaters connected to night-rate tariffs on a per-occupant basis.

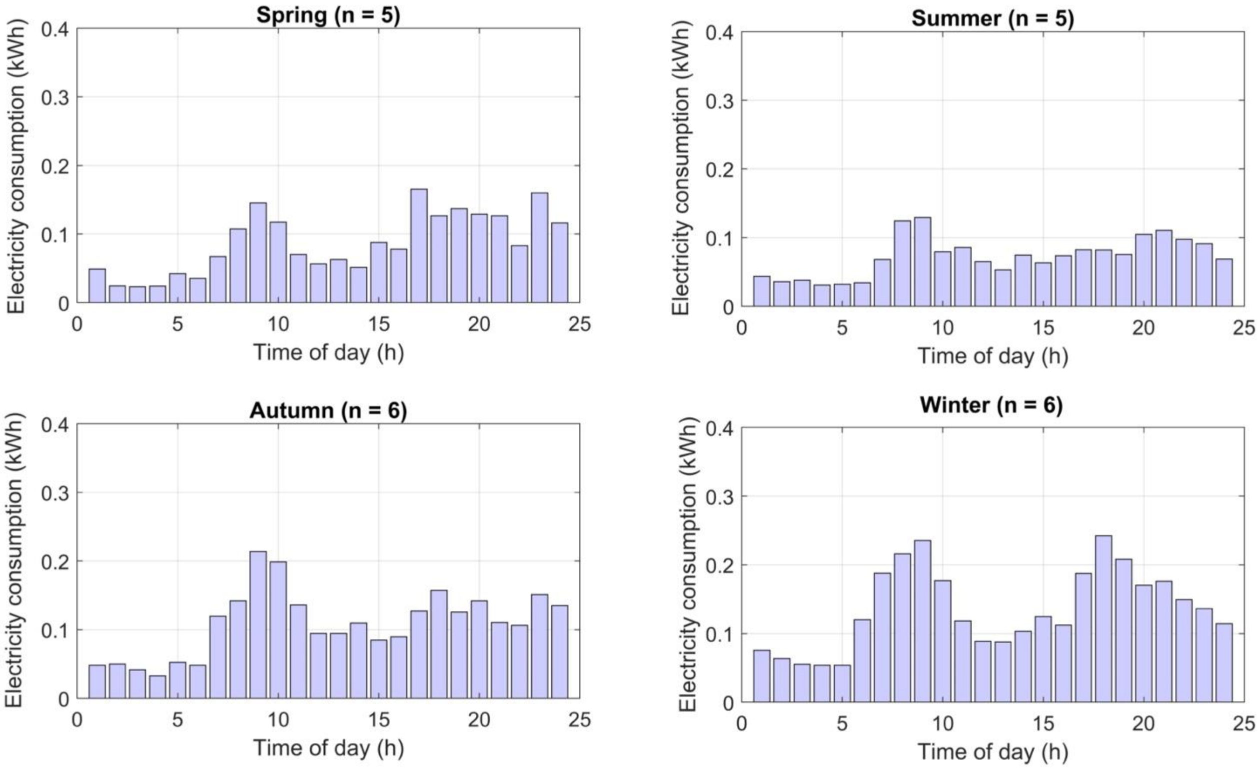

Figure 4 Average hourly electricity consumption per season, standard electric element HW (consumption on a per-occupant basis)

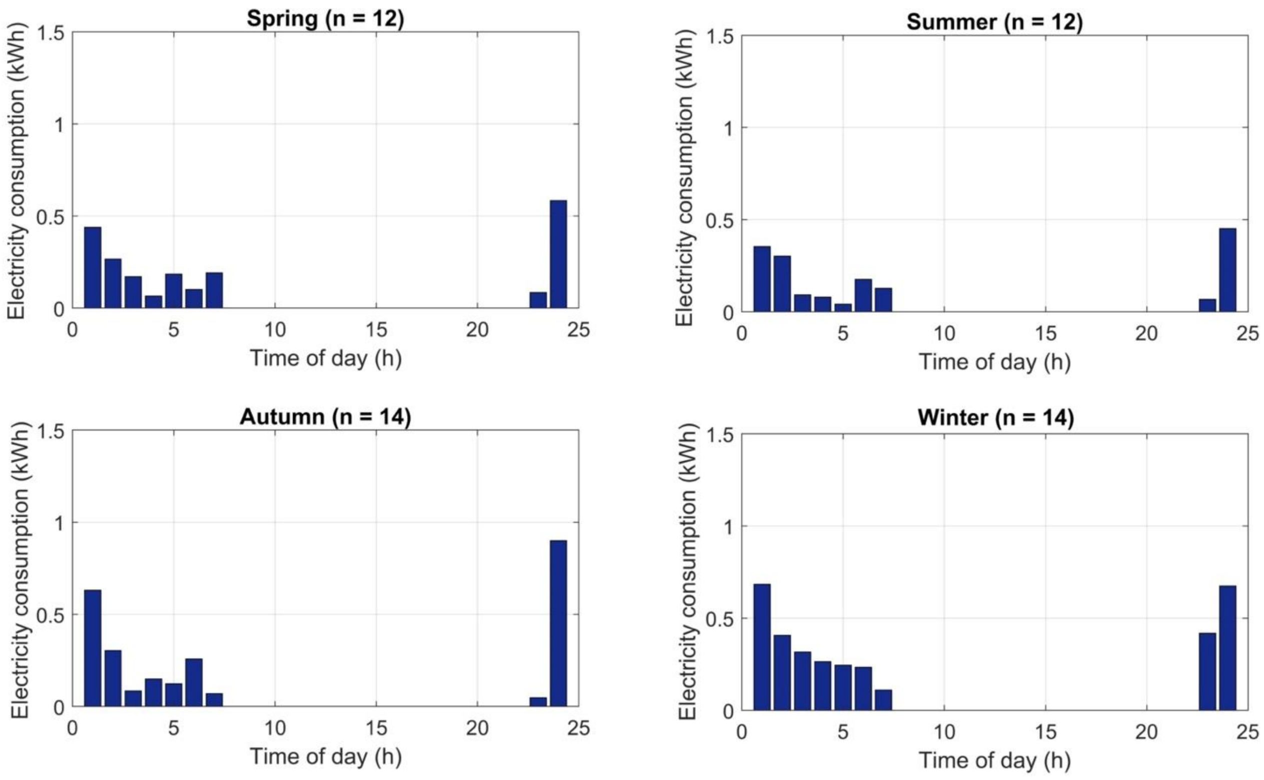

Figure 5 Average hourly electricity consumption per season, controlled standard electric element HW (consumption on a per-occupant basis)

2.2.3 Heat pump water heaters

Figure 6 shows the seasonal average hourly electricity consumption profiles for day-rate heat pump water heaters on a per-occupant basis. As can be inferred from the derived seasonal sub-load profiles, compared to the counterpart profiles for standard electric element water heaters and electric boost elements of SWH systems, the energy required for heat pumps is associated with considerably less sharp morning and evening peak periods throughout the year. This is mainly because, depending on hot water usage and weather conditions, heat pump water heaters run continuously for between 2 and 4 hours per day – though the pump running for 6 straight hours during the coldest nights is not unusual.

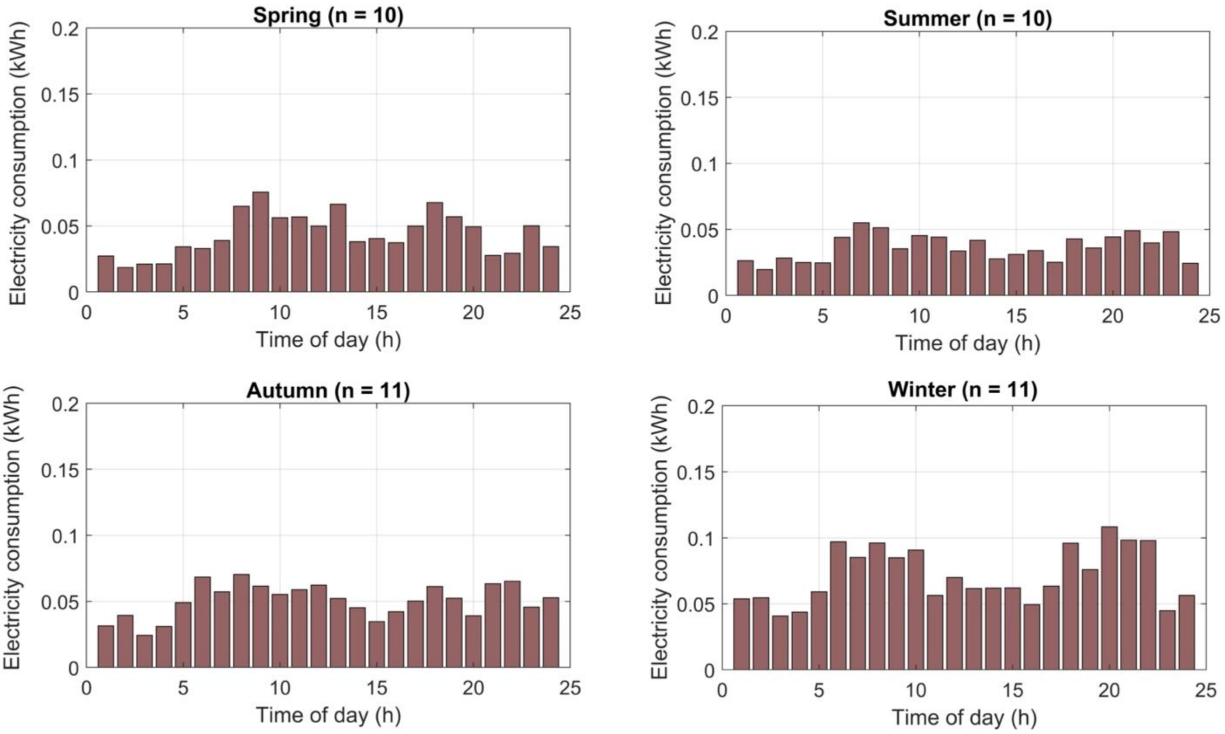

Figure 6 Average hourly electricity consumption per season, heat pump HW (consumption on a per-occupant basis)

Unlike the other two electric water heating systems, from the patterns of electricity consumption, it has been found that controlled heat pump water heaters can be connected to night-rate tariffs or night-rate tariffs with afternoon heating boosts. Accordingly, Figure 7 and Figure 8 respectively display the average hourly electricity consumption per season for controlled heat pump water heaters on night-rate tariffs and night-rate tariffs with afternoon heating boost. A direct comparison of the two sub-load profiles of interest indicates that the estimated values of total consumption for the two classes are nearly the same – about 1.5 kWh per day per occupant on average in spring, 1.2 kWh in summer, 1.6 kWh in autumn, and 2.3 kWh in winter.

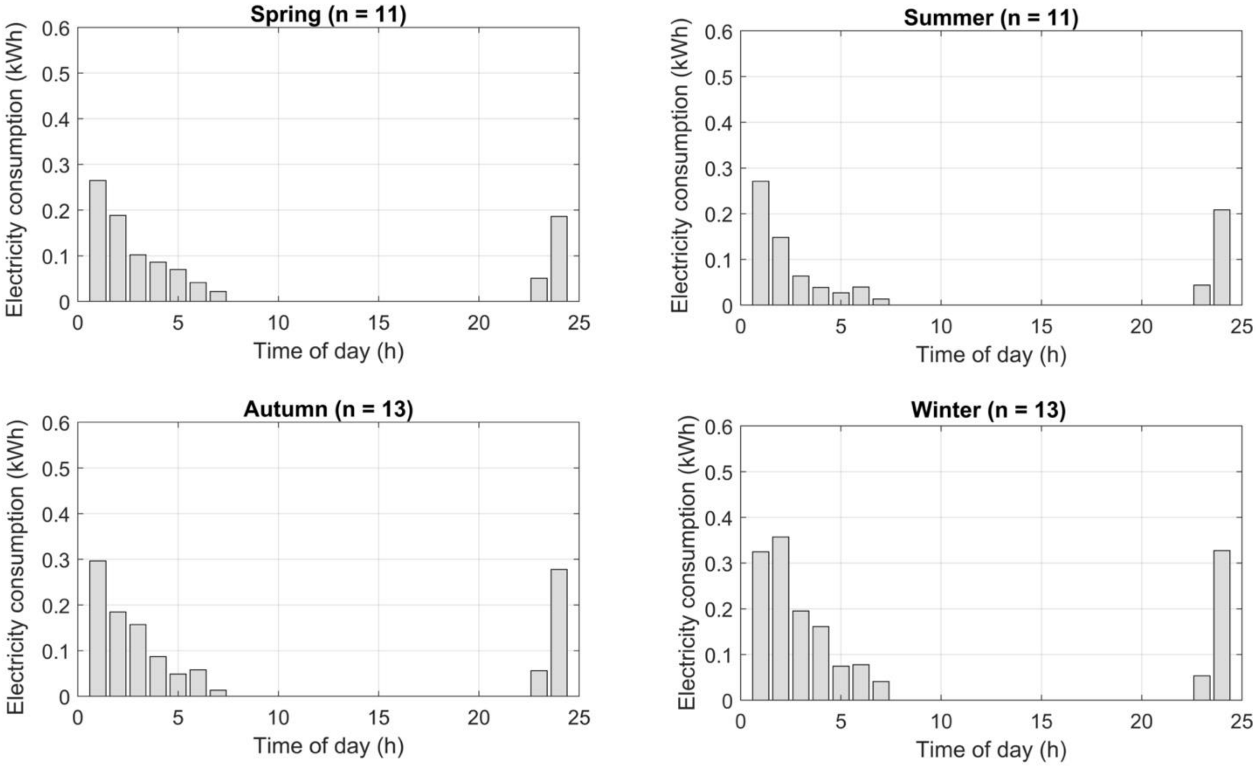

Figure 7 Average hourly electricity consumption per season for heat pump HW (controlled, night) (consumption on a per-occupant basis)

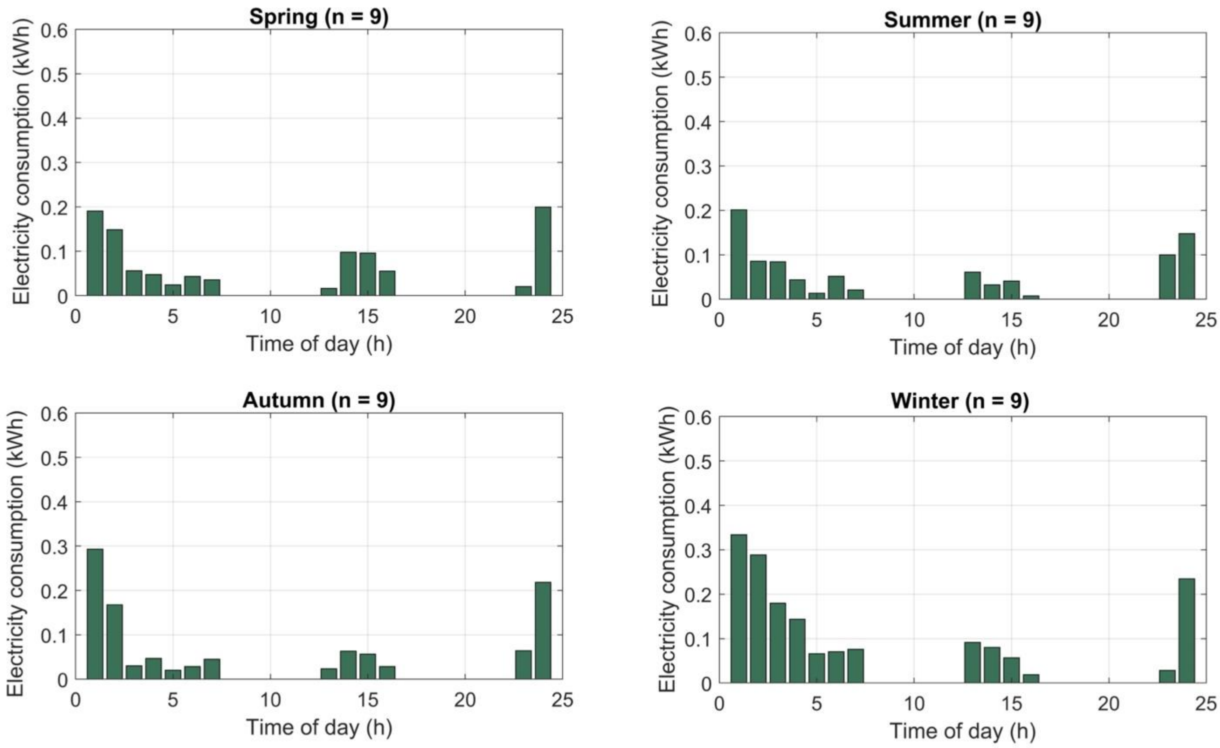

Figure 8 Average hourly electricity consumption per season, heat pump HW (controlled, night/afternoon) (on a per-occupant basis)

2.3 Typical underlying load excluding HVAC and hot water

The typical underlying load excluding HVAC and electric hot water components in Figure 9 represents the average hourly consumption pattern of the underlying load of an average house per season, which illustrates the different times of the day when the total electricity consumption is the highest, particularly in the evening peak hours. The figure reveals a modest degree of variability (see morning and evening peaks) throughout the year, although much more pronounced in the winter evening, which can be attributed to the lighting use. Note that lighting use is concentrated in winter due to fewer daylight hours.

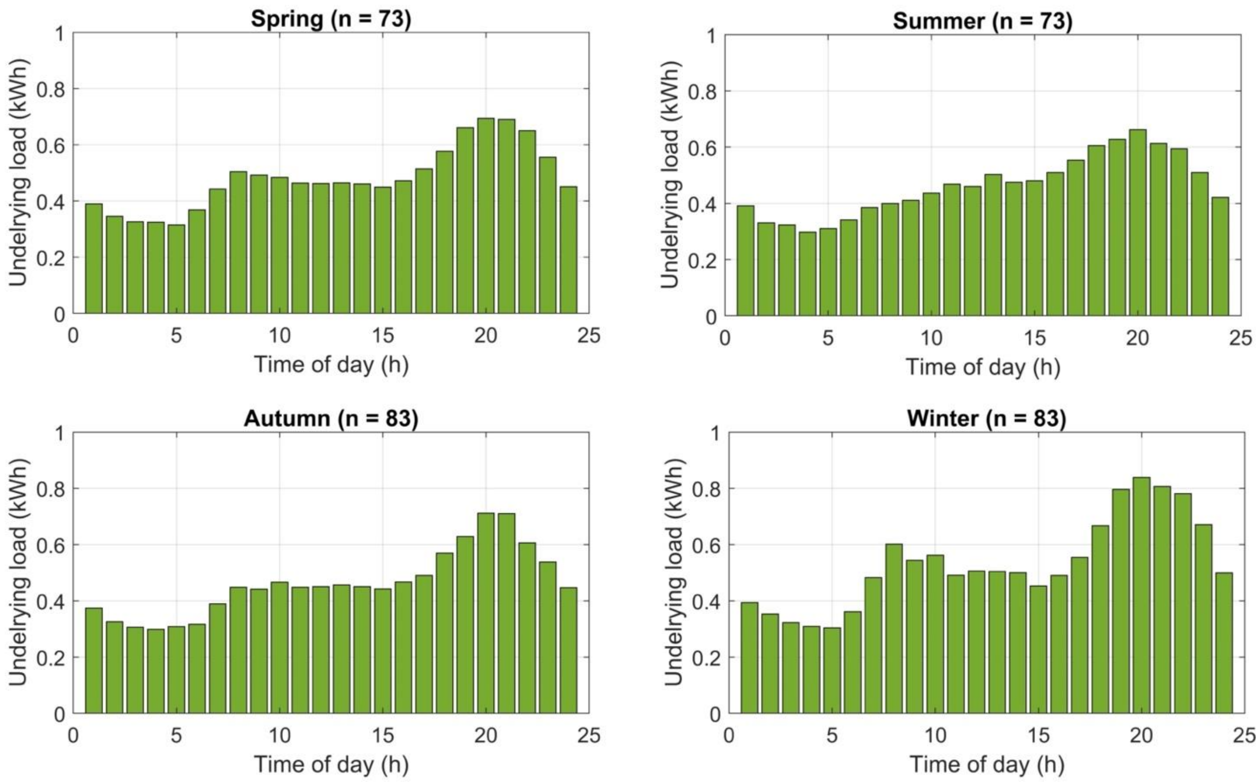

Figure 9 Underlying load of an average house per season

3 Overview of enabling control technologies

Load control technologies can play a significant role in increasing the ability of households to shift loads, reduce demand, or respond to incentives in other ways. They can help to overcome limitations on flexibility that are caused by lifestyle constraints, such as lack of time or being away from home when a response is needed, and can help to overcome a lack of knowledge or understanding about tariffs. They can also allow households to engage in flexibility with minimal inconvenience.

Accordingly, the development, implementation, and integration of control technologies are crucial in order to fully utilise the flexibility potential of households. The following sub-sections provide a brief summary of the characteristics of currently available control technologies for various domestic appliances in the Australian market.[7]

3.1 Timers

Most modern washing machines, clothes dryers, and dishwashers come equipped with an integral timer that allows for the delayed start of a load, which can be used to shift the load to off-peak tariff periods or to increase the use of self-generated solar power. In the appliances without the in-built timer, a relatively low-cost option is to use a mechanical or digital timer, which can be easily placed at the power point for any appliance. Another option is to use switchboard devices for circuits, such as electric hot water, pool pumps, or other circuits, which require installation by a qualified electrician. Also, most heat-pump hot water systems, such as Rheem[8], Sanden[9] or iStore[10], include timing functionality.

3.2 Smart plugs

Another cost-effective and easy-to -install option to control appliances is the use of smart plugs or smart sockets, which enable connecting appliances to Wi-Fi and controlling them through a cell phone application or an online dashboard, thereby providing a platform to schedule the operation of these appliances. Some of these smart plugs even offer real-time or near real-time monitoring and visualisation of energy consumed – and allow for more insights into energy usage patterns. Moreover, these smart plugs are compatible with multiple voice-activated smart home technologies such as Apple HomeKit[11], Amazon Alexa[12], Google Assistant[13], and so forth.

3.3 Smart relays

A number of PV inverter manufacturers, such as Fronius[14] and SolarEdge[15], have also developed a technology that enables monitoring the electricity consumption in a building and activating certain loads, such as electric hot water systems, during times when there is an excess of solar power generation to improve self-consumption.

There are also companies like Wattwatchers[16], Mondo[17], and CatchPower[18] that offer advanced monitoring and control devices which can be used to optimise the use of solar power. For example, Solar Analytics[19] has developed a smart electric hot water control algorithm using Wattwatchers device data. Wattwatchers devices that have the switching capability only need a contactor installed, while devices without the switching capability need a new Auditor and a contactor – with both the device types with and without switching capability requiring installation modifications. CatchPower's Solar Relay[20] also allows for control of circuits and the inverter.

3.4 Smart HVAC control

Smart thermostats, which are widely available in some countries such as the United States, are also gaining interest in Australia. They are designed to replace traditional wall-mounted thermostats. They need to be installed by a qualified installer and have Wi-Fi connectivity which allows for remote temperature setting and scheduling through a cell phone application or an online dashboard. Some models also have features such as energy monitoring and HVAC diagnostics, as well as compatibility with voice control and smart home systems. However, in Australia, due to compatibility issues with ducted air conditioning and split systems, it can be harder to find smart thermostats that work. Some popular HVAC monitoring devices such as

Ecobee[21] and Google Nest[22] are not available or supported, and others such as Zen Thermostat[23] may not work with many common HVAC systems.

There are other alternatives such as Intesis[24] or Sensibo[25], which use infra-red communications to replace or supplement the remote control unit on any HVAC system. These devices can be easily installed by the user, are relatively low-cost, and are compatible with smart home systems and voice control. These devices not only allow for temperature set-points and scheduling of HVAC operation, but also enable different modes (eco, dry, etc) and some such as Sensibo Air[26] also have a feature to connect with motion sensors, which can change the settings based on whether the room is occupied or not.

3.5 Solar diverters

Solar diverters are devices that maximise the self-consumption of solar power by redirecting excess solar power to resistive electric hot water systems. Unlike simple timers, which only turn the electric hot water system on or off, diverters use a technique called Pulse Width Modulation[j] to adjust the amount of power being redirected to match the available excess solar power. This ensures that the electric hot water system uses the most available solar power and minimises the grid import. It is important to note that diverters can only be used with electric hot water systems that use resistance heating, and not heat pumps. Some diverters, like Paladin[27], Powerdiverter[28] and SunMate[29], also take the water temperature into account, while others like CatchPower[30] only divert power when the electric hot water thermostat is on. Most diverters have a manual override setting and some more advanced models can incorporate weather data and sophisticated forecasting techniques in their control algorithm.

3.6 DRED

A demand response enabling device (DRED) is a technology that can be used to manage the electricity consumption of HVAC systems. The DREDs can be connected to the HVAC system and programmed to adjust the temperature, fan speed and other settings to match the energy demand on the grid and energy prices. The DREDs can communicate with the grid operator to receive signals, such as price signals, to adjust the HVAC settings. This way, the HVAC system can be scheduled to operate during off-peak periods or when energy prices are low and reduce its consumption or even shut down during periods of high demand, helping to balance the grid. The use of DREDs in HVAC systems can also result in energy savings for consumers, as well as a reduction in peak demand, which can help to improve the overall efficiency of the electricity grid. PeakSmart program by Energex in South Queensland is an example of using DRED for HVAC control in residential premises.

3.7 Home energy management systems

Home energy management systems (HEMSs) allow customers to monitor, control and manage their energy usage by monitoring their energy flow in real time. The monitoring and control of the appliances takes place by the combination of hardware and software components. Hardware is installed within the property, whereas software is connected via the internet. The user connectivity takes place via online dashboard or an application. The HEMSs can manage the mix of appliances including solar PV, air conditioners, hot water systems, EVs, and battery storage, allowing consumers to ensure that they are using the electricity at the cheapest prices. Technology companies such as Mondo[31], Flow Power[32], and Beat Energy[33] are developing HEMSs for the load flexibility and smart control of the energy appliances.

3.8 Summary

Table 1 and Figure 10 summarise the findings on the enabling technologies for load flexibility with a particular focus on HVAC and hot water systems as flexible load resources. A scan of providers and

[j] Simply put, Pulse Width Modulation (PWM) is a technique used to control the amount of electrical power being supplied to a device. Instead of sending a steady flow of electrical power, PWM sends rapid on-and-off pulses of power to the device. The width (or duration) of the pulses can be adjusted, which effectively changes the amount of power the device is receiving. By changing the width of the pulses, PWM allows for precise control over the power being supplied to a device.

technologies was undertaken to determine costs for this analysis, with additional information in Appendix C Enabling technologies for load flexibility.

Table 1 Summary of load flexibility enabling technologies for HVAC and hot water

Control technology	Type of load	Cost	Customer acceptability/ Ready for implementation
Timers	Hot water	Low ($150 – $200)	Requires licensed electrician for installation
Smart plugs	Hot water and HVAC	Low ($45 – $70)	Easy installation Limited compatibility
Smart relays	Hot water	Medium ($250 – $300)	Requires inspection from licensed electrician before installation to check compatibility
Smart HVAC control	HVAC	Medium ($200 – $350)	Requires inspection from licensed electrician before installation to check compatibility
Solar diverters	Hot water	High ($850 – $1,200)	Need to have solar and resistive hot water system for installation
DRED	HVAC	Low ($100 – $160)	Need assistance from a network provider or utility for the automated control
HEMS	Hot water and HVAC	High ($1,200 – $2,000)	Require high level installation from a licensed electrician

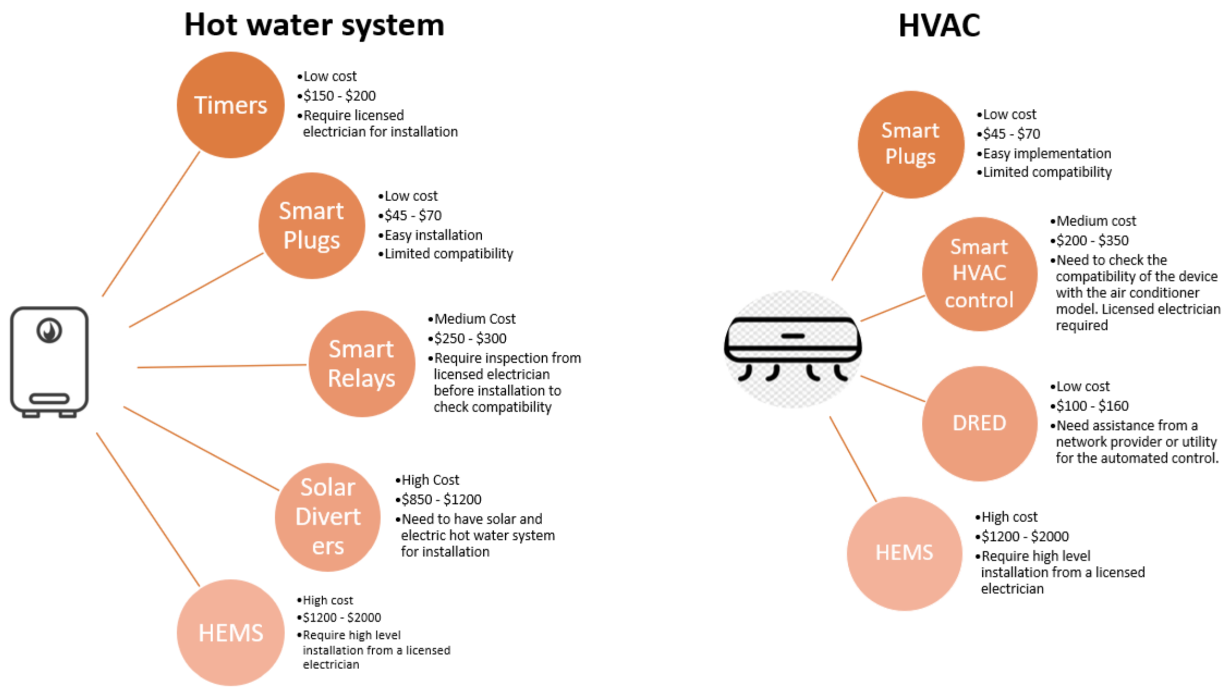

Figure 10 Summary of load flexibility enabling technologies for HVAC and hot water

4 Existing sources of value for flexible loads

Households have several options for participating in markets that allow them to provide electricity flexibility. These markets include the wholesale spot market, network markets, and ancillary services markets. Residential electricity users can access these markets through various methods.[34]

The most common way for households to access markets for providing electricity flexibility is through retail electricity tariffs, which include a wholesale price component as well as regulated network charges for transmission, distribution, and overall network use.

Solar households, also known as "prosumers", have the option to use or sell their own generated electricity. If they sell excess electricity back to the grid, they may receive a fixed or wholesale price-reflective feed-in tariff (FiT) from the retailer. Using electricity flexibility to respond to tariffs can help reduce spot prices in the wholesale electricity market and maintain minimum system-level operational demand, and can also reduce demand on networks during peak times and decrease exports.

Households can also directly participate in the wholesale spot market by using commercially available options through an aggregator or through virtual power plant (VPP) trials with retailers and aggregators. Trials are also available for selected households to use electricity flexibility to directly provide network support to distribution network service providers (DNSPs) and contribute value to ancillary services markets through the provision of frequency control ancillary services (FCAS).

Electricity flexibility can also be leveraged by households to generate value through peer-to-peer (P2P) trading. In P2P markets, households can participate in an electricity marketplace by bidding to either consume or generate electricity. The bids are matched, and the resulting allocation of electricity is determined based on the matched bids.

Additionally, direct load control (DLC) of appliances such as air conditioning units, electric hot water systems, electric vehicles, or pool pumps by a third party is another source of value. Furthermore, behavioural demand response (BDR) is another option where households modify their energy consumption by turning off appliances or adjusting thermostat settings in response to a message from a third party. End-consumers can also participate in a VPP trial, where household battery energy storage systems, electric vehicles, or other appliances are coordinated to provide aggregated demand response to various markets.

This study focuses on the most straightforward ways for households to access markets for providing electricity flexibility, namely retail electricity tariffs and maximising benefit from sunk investment in solar.

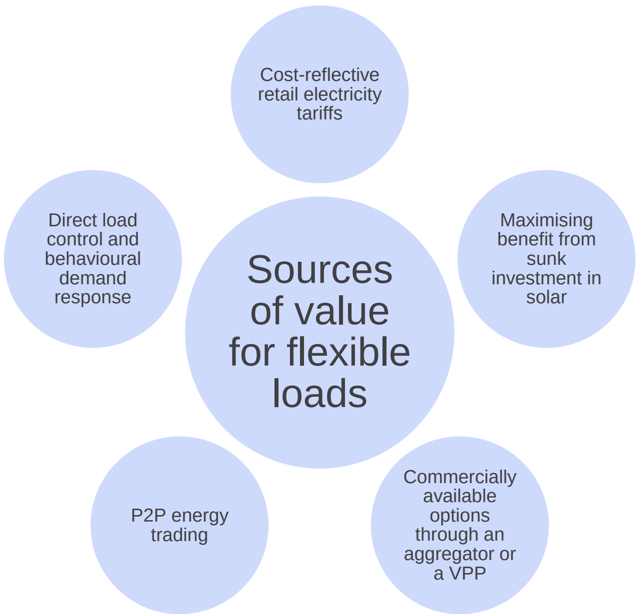

Figure 11 Summary of the sources of value for load flexibility and load control

5 Methodology

To estimate the flexibility potential of residential loads based on appliance-specific load profiles, a specific modelling framework is developed to analyse a number of load shifting scenarios. The developed model is implemented in Gridcognition software[k].

Figure 12 provides a graphical representation of the general load shifting demand response concept, which is used in different variants in this study, noting that the overall consumption stays the same.

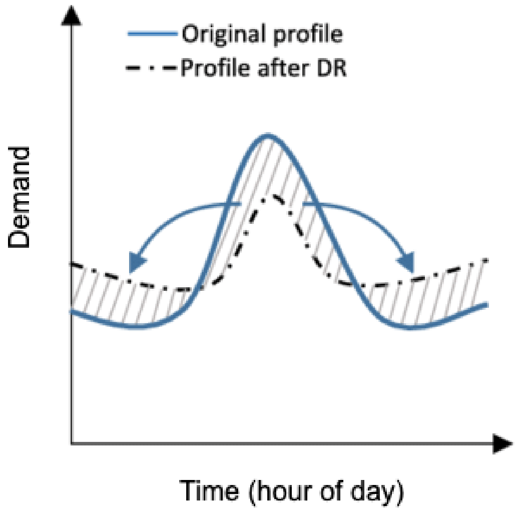

Figure 12 Illustration of the general concept of load shifting demand response[35]

5.1 Methods for quantification of the value of load flexibility elements

5.1.1 What loads were considered?

Given the availability and statistical intensity of appliance-level data, the following sub-loads were considered for load flexibility: (i) HVAC systems, (ii) uncontrolled and controlled heat pump hot water systems, (iii) uncontrolled and controlled standard resistive hot water systems, and (iv) controlled boost element of SWH systems.

Importantly, pure network-led demand response programs – which, for example, would need demand response enabling devices (DREDs) for HVAC systems to control their operation using specific network service provider-generated signals – have not been explored in this study. More broadly, this is consistent with the main objectives of the study which primarily focuses on evaluating the role of load flexibility and control in reducing energy costs and increasing the self-consumption of customers. That is, network benefits do not form a principal part of the scope of the study.

Also, flexing the loads associated with controlled solar boost elements of SWH systems and of customers without solar within AusNet's service territory is not a real option because controlled load tariffs and the off-peak rates of the time-of-use (ToU) tariff are virtually the same.

Further, the uncontrolled (day-rate) SWH with electric boost systems were not modelled because an analysis of the Wattwatchers monitoring device data has found them to be rare hot water system types in Heyfield.

Moreover, given that the controlled load tariffs and off-peak rates are practically the same, flexing the controlled loads was not deemed to be beneficial for customers without solar, and therefore not modelled.

[k] Gridcognition Simulation & Optimisation Engine integrates rigorously tested parametric models for multiple kinds of energy resources, a billing-grade pricing and rating engine for commercial calculations, and an advanced optimiser to accurately represent the control system that will orchestrate and optimise the energy resources. For more information, see the following link: https://gridcog.com/

In addition, all the analyses were carried out for an average household. Accordingly, the hot water sub-load was adjusted for a household size of 2.5 people[36]. Also note that in deriving the underlying hot water sub-load time-series data per person, unless it was explicitly stated in the linked Ecologic data, an average household size of 2.5 people was considered.

It is also noteworthy that the average size of standard element hot water systems is 3.6 kW. Also, heat pump hot water systems with an average nameplate capacity of 0.84 kW are considered. Furthermore, the average nominal capacity of the booster heating element of SWH systems is 1.5 kW, while the average size of the HVAC in the lounge of large houses is 7 kW.

5.1.2 Value flows

In general, the value flow configuration illustrated in Figure 13 for the interactions of customers, retailer, and the network was considered.

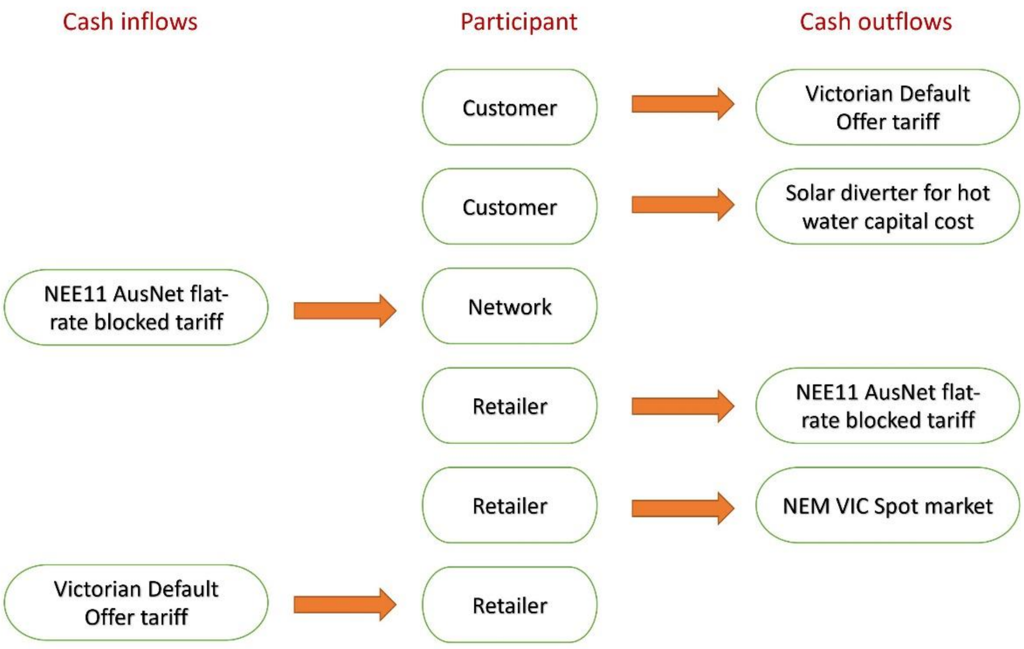

Figure 13 Illustration of the value flow configuration in the Gridcognition software environment

It is also noteworthy that the preliminary test case scenarios indicated that exposure to the FCAS market would only result in trivial savings (about $5–$10) for the cases defined. Therefore, they were not considered in the final model instances.

5.1.3 Tariffs

It is important to analyse both flat-rate and time-of-use tariffs because they represent two different pricing models for electricity that can impact household electricity bills. Flat-rate tariffs charge a single, fixed price per unit of electricity consumed, regardless of the time of day. However, they do not incentivize energy conservation or demand management. Time-of-use tariffs, on the other hand, charge different prices for electricity depending on the time of day it is consumed. This pricing model is designed to incentivize households to shift their electricity consumption to off-peak periods, when demand is lower and the cost of electricity is cheaper. By analysing both types of tariffs, energy market participants can better understand the potential for demand management and cost savings (i.e. impacts on household electricity bills) to develop strategies to optimise energy consumption and manage demand.

It is also noteworthy that, in this study, it was assumed that the customers that are currently on the flat-rate tariff will be switched to the ToU tariff if they want to control their flexible load resources, while the customers on the ToU tariff will remain on the same tariff. Also for the hot water systems currently connected to a controlled load tariff, it is assumed that they will be moved off the associated controlled load tariff to the ToU tariff.

5.1.4 Modelling customers with and without solar

To account for the differences in terms of the orientation and tilt angle of rooftop solar PV systems installed in Heyfield, it was decided to use the mean hourly solar PV generation data (8,760 data points) across the entire fleet of 53 Wattwatchers devices that include solar data in the model, as opposed to specifying the system size in the simulation software package.

The peak value of the solar generation profile from taking the average of the solar generation associated with all relevant device data is ~4 kW_p. Accordingly, the solar PV data represent an average size of ~4 kW_p for residential rooftop solar PV generation systems in Heyfield. Using the data from onsite monitoring devices helps improve the accuracy of the model by better corresponding solar generation data with load data – reflecting the fact that solar generation and load data are correlated to some extent. This is because, in the process of deriving the underlying load, the gross solar generation is added back to the grid imports for customers with solar to appropriately account for the net-metering settings, before subtracting the electric space and water heating sub-loads from the overall load. Also note that if the solar generation data was built by the dedicated module of the analytic engine, then it would have been restricted to a certain orientation and tilt angle making it less representative of the houses in Heyfield with solar PV.

The cases without rooftop solar PV are modelled considering the underlying load (i.e. general power), hot water sub-load, and HVAC sub-load separately. However, in the cases with solar PV, due to the intertwined interactions between various parameters, including onsite solar generation, underlying load, controllable sub-loads (where appropriate), and the applicable rates, the modelling is carried out in an integrated manner to achieve household-level system-wide optimality. In this setting, the customers with solar are classified into the following categories: (i) Underlying load + Hot water sub-load (with and without load flex), (ii) Underlying load + HVAC sub-load (with and without load flex), and (iii) Underlying load + Hot water sub-load + HVAC sub-load (with and without load flex).

5.1.5 Load schedules

The flexible load schedule for the uncontrolled hot water systems of customers with and without solar is defined as follows: shift the relevant sub-load from the peak period 3 p.m.–9 p.m. to the period 8 a.m.–2 p.m. A similar load flex strategy has been implemented for currently controlled hot water systems. Note that because at the customer level, the retail prices are not reflective of wholesale energy market prices, as well as the fact that Gridcognition software yields the flattest possible curve (i.e. a line in this setting) as the optimal load flex solution, it was decided to restrict the operational hours of electric hot water systems in the flexed mode to daytime hours to be closer to peak hot water usage hours (i.e. evenings). Not only will this allow for reducing the heat losses of storage tanks, but it will also provide a platform to adequately represent the several hours-long operational cycles of heat pump hot water systems. Also note that because in the flexed mode, off-peak charges of the ToU tariff are applied, shifting the relevant load to any time period but 3 p.m.–9 p.m. will lead to the same results in terms of total customer charges.

A similar flexible load schedule is considered for HVAC systems of customers without solar by shutting them down during the 3 p.m.–9 p.m. time period and moving the relevant load to the period 10 a.m.–2 p.m. The average size of the HVAC in the lounge of large houses (7 kW) has been found to be able to meet the original total power consumption in the period 3 p.m.–9 p.m. moved to the preceding hours – in addition to the original load on those preceding hours. However, there are two drawbacks to this approach: Firstly, drawing the same amount of power by the HVAC systems in the new time window will lead to different indoor temperatures during the period 10 a.m.–2 p.m. That is, the occupants might feel cold during the pre-cooling hours in the summertime and feel overly warm during the pre-heating hours in the wintertime. Secondly, all the analyses of flexing HVAC loads are made under the simplifying assumption that the houses are well-insulated and, therefore, the HVAC systems have the potential to be turned off for 7 hours[37] without having a considerable impact on the thermal comfort of occupants. That is, producing the best trade-off between maximising customer comfort and minimising the charges attributable to the HVAC load would require more detailed studies on the value the customer places on thermal comfort and the associated home energy star ratings, which are deemed beyond the scope of this study.

For customers with solar, the HVAC load occurring in the period 3 p.m.–9 p.m. is shifted back to the period 10 a.m.–3 p.m.[i] for the analytic engine to optimise the schedule of the HVAC system by determining the best combination of using onsite solar generation and the off-peak rate of the ToU tariff subject to the HVAC capacity (kW). Given the parameter settings (FiT and charges), the analytic engine in the studied cases is expected to prioritise self-consumption over grid imports. That is, PV generations should first serve the household loads and any excess generation should be exported to the grid. If PV generation is insufficient, the remainder of the load should then be met by importing from the grid.

Figure 14 provides a summary of the flexible load schedules specifically developed for uncontrolled and controlled hot water systems and (uncontrolled) HVAC systems of customers with and without solar.

- Uncontrolled hot water systems of customers with and without solar: shift the relevant sub-load from the peak period 3 p.m.–9 p.m. to the period 8 a.m.–2 p.m.
- Controlled hot water systems of customers with and without solar: Shift the relevant sub-load from controlled load hours to the period 8 a.m.–2 p.m.
- HVAC systems of customers without solar: shift the relevant sub-load from the peak period 3 p.m.–9 p.m. to the period 10 a.m.–2 p.m.
- HVAC systems of customers with solar: shift the relevant sub-load from the peak period 3 p.m.–9 p.m. to the period 10 a.m.–3 p.m.
- All HVAC systems: calculate likely use of HVAC outside of off peak times to account for additional input needed to maintain comfort.

Figure 14 Summary of the developed flexible load schedules

5.1.6 Accounting for heat losses in modelling HVAC load flexibility

A review of the literature has identified that while different building types are associated with different thermal mass and insultation characteristics, the efficiency of pre-cooling and pre-heating decreases significantly with an increase in length of the load shifting event. For example, it has been found that the solid concrete wall has had 93% storage efficiency, compared to a cavity wall, which has 81% storage efficiency for a 4-hour demand response event[38].

Accordingly, to factor in the associated heat losses, it has been assumed that a certain percentage of original loads is additionally added to the peak hours (3 p.m. to 9 p.m.). Table 2 presents the percentage of original load added back to the peak hours.

[i] Because of the existence of solar PV, the ending hour of the time window to which the original HVAC load is shifted back is 3 p.m. to enable benefiting from solar generation at that hour (where appropriate) – compared to the case without solar where it is set to 2 p.m., which is the last hour before the start of the peak tariff. Also note that in the case with solar, if the time window to which the original HVAC load is shifted to any hour later than 3 p.m., then the pre-cooling/ pre-heating can no longer be ensured. That is, the model might decide to undertake intractable post-cooling/ post-heating – and we cannot know from the results if that has been the case.

Table 2 Percentage of original load added back to the same peak hour to account for heat losses

Peak hour	Percentage of original load
3 p.m.	0%
4 p.m.	10%
5 p.m.	12%
6 p.m.	14%
7 p.m.	16%
8 p.m.	18%
9 p.m.	20%

5.2 Key assumptions

Table 3 summarises the key assumptions used in this study for the explored tariffs, the cost of enablement technologies, and the general modelling assumptions.

Table 3 Summary of key assumptions

Parameter	Value(s) used in modelling	Comment/ source
Residential electricity tariff	**Service charge** $1.2994/ day **Time of use** 0.4081 $/kWh peak 0.1965 $/kWh off-peak **Flat rate** 0.2893 $/kWh (first 1.02 MWh per quarter) 0.3070 $/kWh (subsequent usage) **Controlled load** 0.1962 $/kWh	Victorian Default Offer Rates[39] for AusNet Services area
Network tariff	**Service charge** $125.07/ year **Time of use** 0.2291 $/kWh 3pm-9pm weekdays 0.0477 $/kWh all other times **Flat rate** 0.1272 $/kWh **Controlled load** 0.0475 $/kWh controlled load	Enables calculation of stakeholder outcomes to include network business and retailer
Environmental costs	**Environmental fixed cost** $16.375/customer **Environmental variable cost** $0.0284/kWh	Victorian Default Offer Rates[40]
Feed in tariff[m]	$0.05/kWh	Minimum feed in tariff set by Essential Services Commission[41]
Distribution loss factor	7.12%	Approved network average distribution loss factor in AusNet Services' network[42]
Establishment cost for electric resistive water heaters/	Solar diverters $1,025 (capital) $400 (installation)	Mid-range value of $850-$1,200 capital and $200-600 installation & smart meter rewiring found in the market scan.

[m] Note that the current premium FiT of $0.60/kWh expires in 2023 or 2024 depending on the start date, and therefore, not considered in this study.

Parameter	Value(s) used in modelling	Comment/ source
SWH electric boost, customers with solar PV	$1,425 (total)	Note: solar diverters are not compatible with heat pumps or HVAC systems
Establishment cost for electric resistive water heaters/ SWH electric boost, customers without solar PV	Hot water timers $175 (capital) $150 (installation) $325 (total)	Mid-range value of $150-$200 capital and $100-$200 installation found in the market scan
Establishment cost heat pump / HVAC systems	$0	Heat pumps and HVAC generally come with built-in timers[43]
Time period of the original data used	One year from July 2021 to June 2022 with hourly resolution	In accordance with the Wattwatchers data retrieved for the associated load profiling study
Project lifetime/ planning horizon	10 years	January 2024 to December 2033
Discount rate	4%	The recommended discount rate for Commonwealth infrastructure projects[44]

6 Results

The section presents a comparative analysis of the modelling results around the impact of load flexibility based on the developed load shifting strategies on the residential customers' electricity bills on an average annual basis for various customer types – including those with/ without solar and various sources of load flexibility.

6.1 Overview

Figure 15 provides an overview of the impact of implementing the load flexibility schedules on the average annual customer bills. All customers are assumed to have HVAC, and various electric water heating types are shown. Customers with and without solar are shown. The base case assumes a flat-rate tariff.

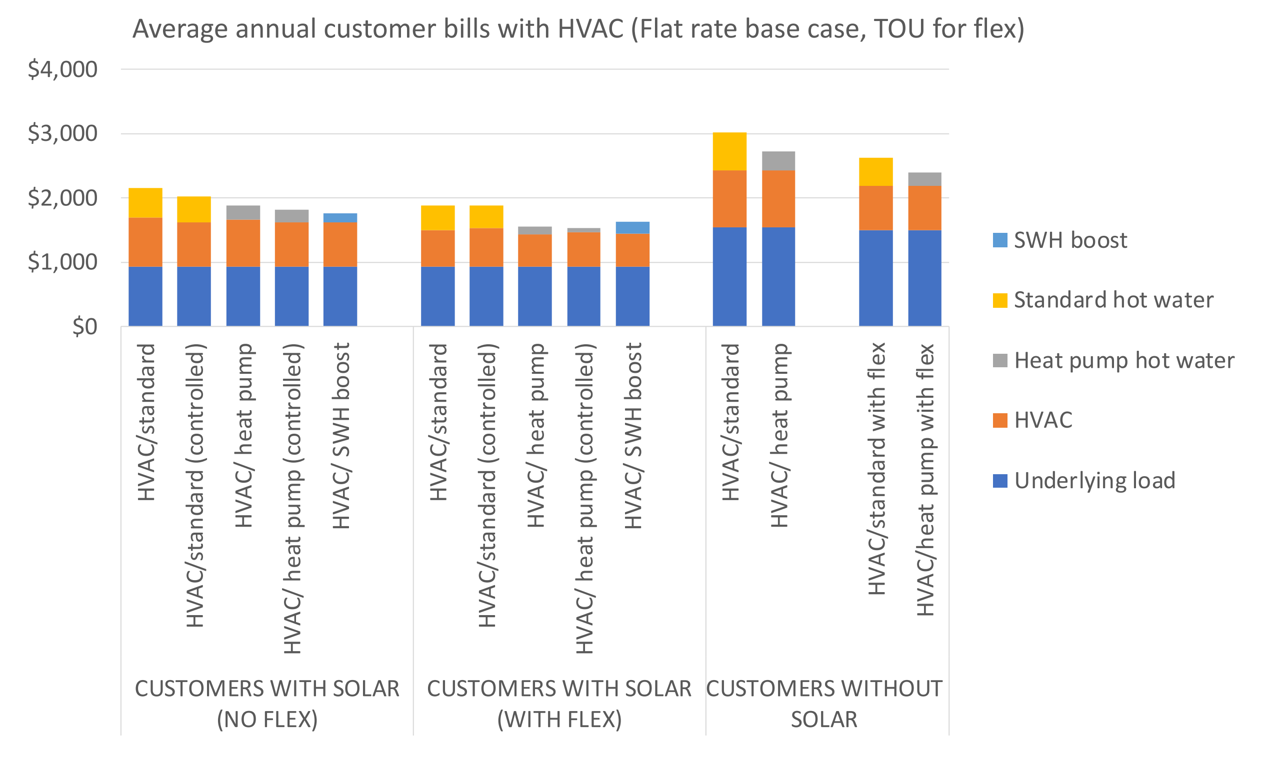

Figure 15 Overview of average annual customer bills with HVAC and electric water heating

Throughout this report, the term "controlled load" refers to the electricity supplied to the separately metered hot water systems on a dedicated controlled load connection – and is associated with a specific lower rate under both flat-rate and ToU settings – whereas the term "flexed load" refers to the shifted electricity consumption of discretionary sub-loads to lower-priced hours under the ToU setting. In this setting, the term "flexed controlled load" refers to the load that is connected to a controlled load tariff and has undergone load flexibility – and has been shifted to off-peak hours.

A comparative analysis of the results provides the following insights:

- HVAC and standard resistive electric element water heating systems[n] are the most likely loads to be used for tariff-oriented load shifting. However, many households do not have a resistive electric element hot water system available to provide flexibility, either because they have gas

[n] Note that we have factored in a total of $325 for hot water timers and $1,425 for hot water diverters as the establishment costs, which are applied to the resistive loads (standard element hot water systems and boosting elements of SWH systems) of customers without solar and with solar, respectively. That is, excluding these costs and assuming the same level of control across all flexible loads considered, improves the comparative savings expected from flexing such loads.

hot water, heat pump hot water, or electrically-boosted SWH. Also, with gas and wood space heating available in Heyfield, not all households have large HVAC loads in the wintertime.

- Both households with and without solar can significantly benefit from load flexibility.

- Load shifting using the developed load schedules improves solar self-consumption for solar households. The financial driver for increasing solar self-consumption is the difference between the FiT offered for exports and the tariff charged for grid consumption.

6.2 Impact of HVAC and water heating flexibility on customers' bills

Figure 16 and Figure 17 summarise the impact of load flexibility for HVAC and for water heating on electricity bills for solar and non-solar customers which are currently on a flat-rate tariff[o].

6.2.1 Savings from flexing HVAC

Potential savings from implementing flexibility for HVAC systems are shown in Table 4.

For customers with solar, potential savings vary from $83 to $226. These savings are driven mainly by meeting part of the HVAC load from their own solar generation, and partly by reducing the tariff from the flat rate to the off-peak rate for whatever HVAC load is not met by self-generation. The is why the savings vary according to the type of water heating; the smaller the midday load of the water heater, the larger proportion of HVAC load can be met by the solar. This is reflected by the differences in savings. The low savings for customers with controlled load is because the base case bill for HVAC is much lower, as a significant proportion of HVAC load will be met by solar even without flexibility.

Figure 16 shows customer bills for HVAC, with and without flexibility. The amount shown for customers with solar is the average ($713 per year) for all five types of water heating, while the error bars show the maximum and minimum bills ($768 for customers with standard uncontrolled water heaters and $688 for customers with controlled load standard water heaters).

For customers without solar, the HVAC proportion of their bill remains constant, at $878, with estimated savings of $192.

Comparable results are obtained for the customers currently on the ToU tariff, presented in Appendix A.

Table 4 Potential savings from implementing HVAC flexibility

	CUSTOMERS WITH SOLAR						CUSTOMERS WITHOUT SOLAR	
Type of water heating	Heat pump	Heat pump (controlled)	Standard	Standard (controlled)	SWH boost		Standard	Heat pump
Savings from flexing HVAC	$226	$154	$203	$83	$178		$192	$192

[o] Note that the customer charges attributable to electric hot water and HVAC systems alone exclude fixed daily charges as they have been applied while calculating the charges relevant to the underlying load.

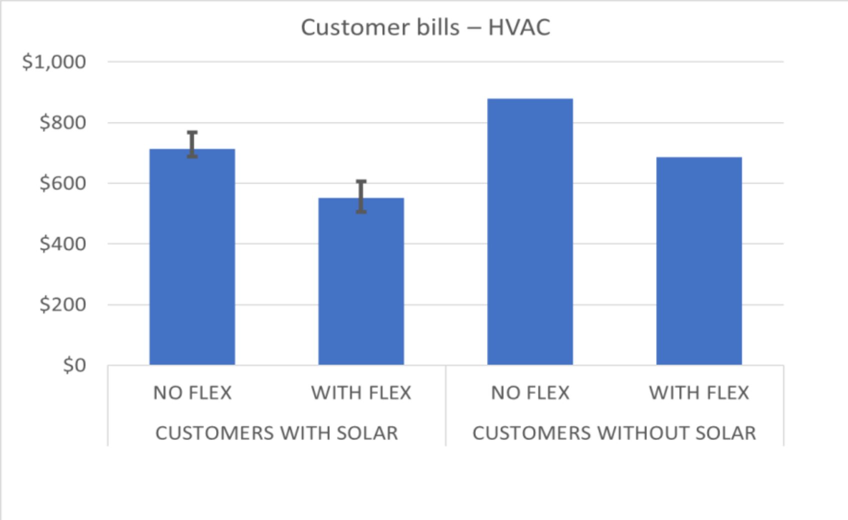

Figure 16 Average annual customer bill for HVAC

6.2.2 Savings from flexing water heating

Figure 17 shows the average bills for different types of water heating, with and without flexibility.

In all cases bills are highest for standard element water heaters, followed by heat pumps, with SWH with electric boost the lowest.

For customers without solar, there is a large difference between controlled and uncontrolled hot water, reflecting the difference between flat rate and off-peak rates. The insignificant difference in the customer bills associated with the uncontrolled and controlled standard element hot water systems for customers with solar is because a significant proportion of uncontrolled standard element is served by onsite solar generation.

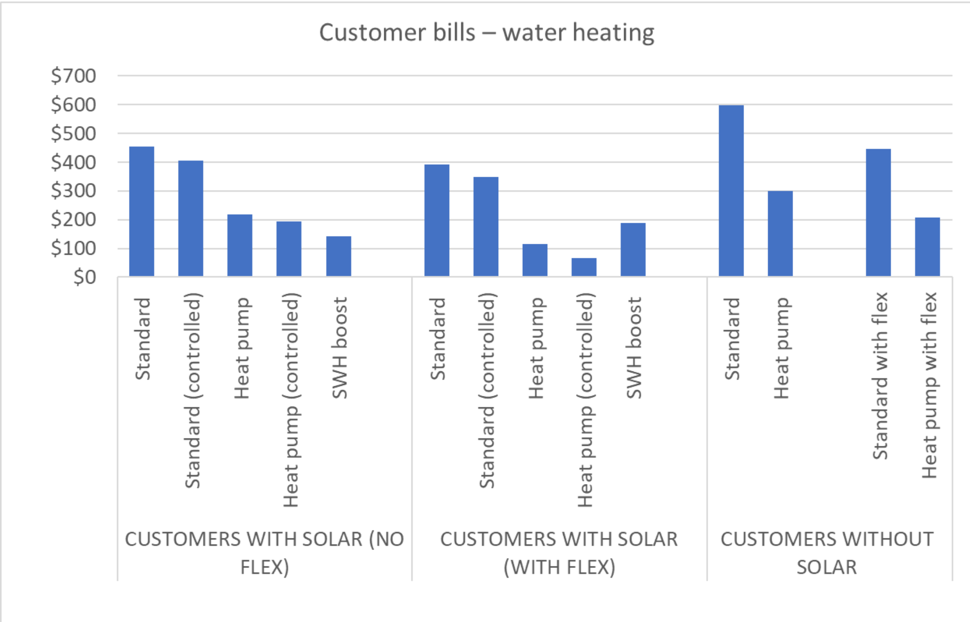

Figure 17 Average annual customer bill for water heating

Potential savings for implementing flexibility for different types of water heating shown in Table 5.

The greatest savings from flexibility are for customers without solar, with uncontrolled standard element water heaters. This is followed by controlled standard element heat pump water heaters for customers with solar. We did not analyse applying flexibility to controlled water heating for customers without solar as there would be no scope for savings, as their water heating load is already on the lowest tariff available and there is no ability to increase self-consumption.

Customers with controlled electrically-boosted SWH systems will be worse off by applying the flexibility scheme. Specifically, the savings generated from flexing the controlled solar boost load for customers currently on FiT over the 10-year period (i.e., $777) are not able to recoup the cost of the solar diverter (i.e., $1,425); hence, the total cost of the case with load flex is $648 greater than the case without load flex.

Table 5 Potential savings from implementing water heating flexibility

	CUSTOMERS WITH SOLAR						CUSTOMERS WITHOUT SOLAR	
Type of water heating	Heat pump	Heat pump (controlled)	Standard	Standard (controlled)	SWH boost		Standard	Heat pump
Savings from flexing water heating	$103	$128	$65	$59	-$47		$151	$92

Comparable results are obtained for the customers currently on a ToU tariff, presented in Appendix A.

6.3 Results by stakeholder

6.3.1 Network business

Figure 18 shows the average annual network charges for various customer types – who are currently on the flat-rate tariff[p] – broken down into the charges associated with the constituent sub-loads[q]. The results are revealing in the following ways:

- The network business may be worse off in terms of network charges with load flexibility. Retailers are responsible for collecting network charges from residential customers, and these can represent about 40%–50% of total bills in the absence of flexible loads[45]. Much of the savings in electricity bills from load flexibility are attributable to the reduction in network charges. However, as peak demand is the most significant driver of network costs, implementing load flexibility programs may well be beneficial to the network business in the long run and provide cost savings for consumers via lower network investment.

- HVAC loads are high energy consumers in residential buildings, and therefore, can be a significant driver of peak loads. By adjusting the operation of HVAC systems, network operators can shift energy consumption away from times of high demand, reducing the need for additional power generation and transmission capacity. This, in turn, can lead to reductions in network charges. Controlling the high-consuming HVAC systems can help utilities avoid costly upgrades to their infrastructure. To this end, HVAC systems can be retrofitted with a demand response enabling device (DRED) to allow the electricity provider to control the system at various pre-programmed levels and manage the demand on the power grid during peak periods.

- Peak demand is a significant factor in determining the amount of investment required and total network costs. This means that load flexibility is becoming increasingly important as the integration of new technologies, such as electric vehicles (EVs), is expected to cause a significant increase in future loads on the power grid. By participating in load flexibility and control programs, end-users can

[p] Comparable results are obtained for the customers currently on the ToU tariff.
[q] The retail margin is estimated by subtracting the modelled wholesale energy cost, network charges, environmental charges, and any costs attributable to the load flexibility enabling technologies (where appropriate), which are assumed to be incurred by the customers.

help to defer or deter capital-intensive network investments that would otherwise be necessary to meet the increased demand from EVs and other technologies.

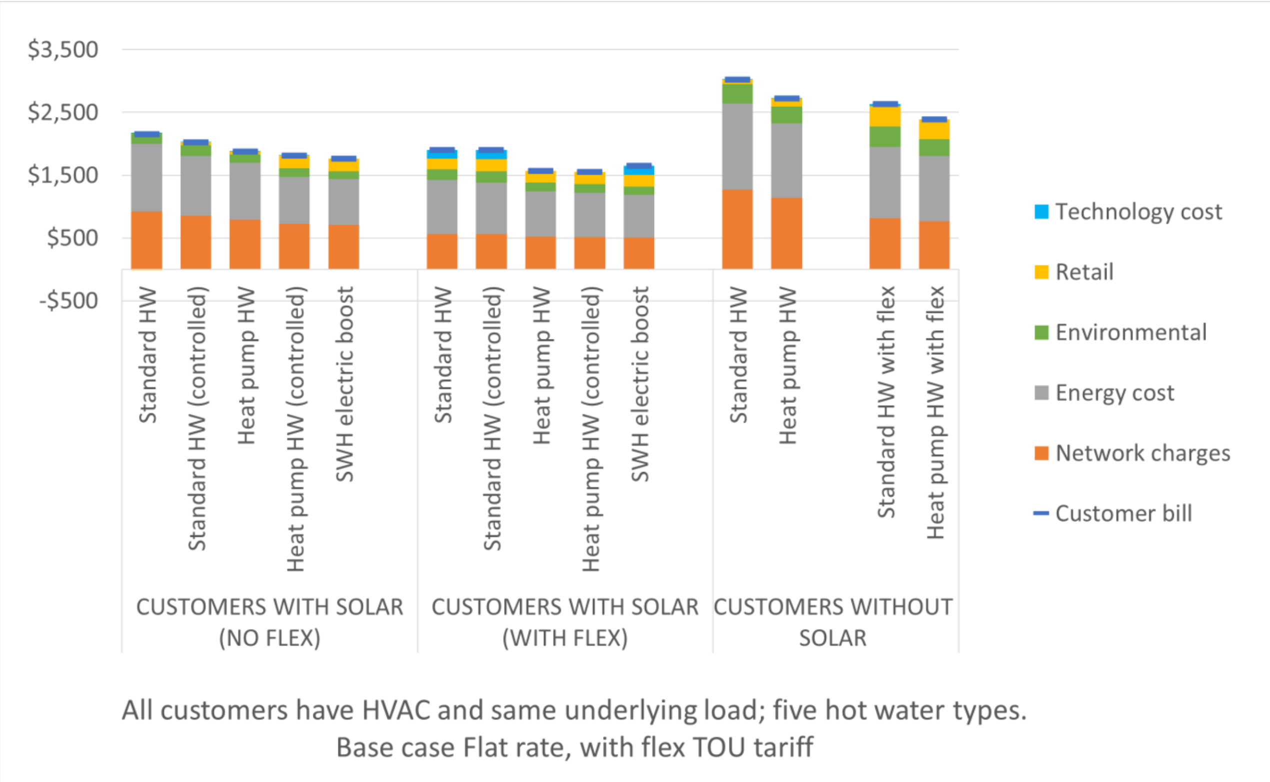

Figure 18 Stakeholder analysis for load flexibility (base case flat-rate, load flexibility ToU tariff)

6.3.2 Retailer

Figure 18 also shows the average annual retailer margin for various customer types. As explained in the methodology section, in terms of the cash flows of the retailer, for the sake of simplification, it is assumed the retailer purchases the electricity from the wholesale electricity market (spot market)[r] and pays the network charges to the network service provider, while the customers are charged with retailer charges.

The following insights emerge from the summary of retailer margin results in Figure 18:

- The retailer makes a loss (albeit negligible) in the base case when selling electricity to customers with solar, HVAC and uncontrolled standard resistive hot water systems in the absence of load flexibility. Generally, the customers with solar need less electricity to purchase from the retailer due to onsite solar PV generation, and the retailer earns less revenue from electricity sales to these customers compared to non-solar customers.

- For electricity retailers, load flexibility can improve margins in serving both customers with and without solar by allowing them to better manage supply and demand. For example, during times of high electricity demand, retailers must purchase additional electricity from the wholesale market, which can be more expensive than the electricity they already have under contract. By having customers with load flexibility, retailers can encourage them to shift their consumption to times of lower demand, reducing the need to purchase additional electricity and thus saving money on wholesale costs.

- Load flexibility can help retailers to take advantage of price differences between different times of the day, such as the ToU pricing, where the electricity is cheaper at certain hours, as explained

[r] That is, it is not assumed that the retailer has a contract with electricity generators and purchases the additional electricity – on top of the electricity they already have under contract – from the more expensive wholesale market.

above. By encouraging customers to shift their consumption to these cheaper hours, retailers can reduce their wholesale costs and pass on some of the savings to customers.

The results confirm that, in addition to the lack of control over the cost of electricity, electricity retailers have thin margins. With many retailers operating, competition is intense, making it difficult for any single retailer to charge significantly higher prices than its competitors. As a result, retailers are often forced to offer competitive prices and promotions to attract and retain customers. Additionally, the regulatory environment for electricity retailing is very stringent and can often limit the retailers' ability to generate significant margins. All these factors combined make it challenging for electricity retailers to generate significant margins, and makes customers implementing flexibility attractive.

6.4 Washing machines and dishwashers

We did not have load profiles for plug in appliances, such as washing machines and dish washers, as these are not monitored separately. We have estimated potential savings from using these during times of solar generation for customers with solar and note that if customers switch from flat rate to time-of-use tariffs it will be important to keep usage of these appliances out of peak times as far as possible.

The CSIRO's Residential Study Baseline Study suggests that the total annual consumption of dish washers and washing machines (per dwelling that has them) equals 156.26 kWh and 92.32 kWh, respectively[46].

Three scenarios were modelled to estimate the impact of shifting the usage of dish washers and washing machines with the aim of increasing self-consumption for customers with solar, namely:

- 0% self-consumption: washing machines and dishwashers are used outside of generation times
- 50% self-consumption: 50% of usage is met by solar generation
- 100% self-consumption: all washing machines and dishwashers use is met by solar generation.

A flat-rate tariff and three ToU tariff cases were considered: (1) all usage occurs during the off-peak period (best-case), (2) half of the usage occurs during the off-peak period with the other half occurring during the peak period (mid-case), and (3) all usage occurs during the peak period (worst-case).

To account for the value of excess solar, the "cost" of running the appliance on self-consumption is taken as the value of the FiT ($/kWh) that the household would have received if sent back its excess solar to the grid.

Figure 19 and Figure 20 summarise the total annual charges for dish washers and washing machines. Flexing the usage of dish washers and washing machines to best match the availability of onsite solar has the potential to reduce customers electricity bills by approximately $60/year and $35/year respectively, demonstrating that their impact is relatively small.

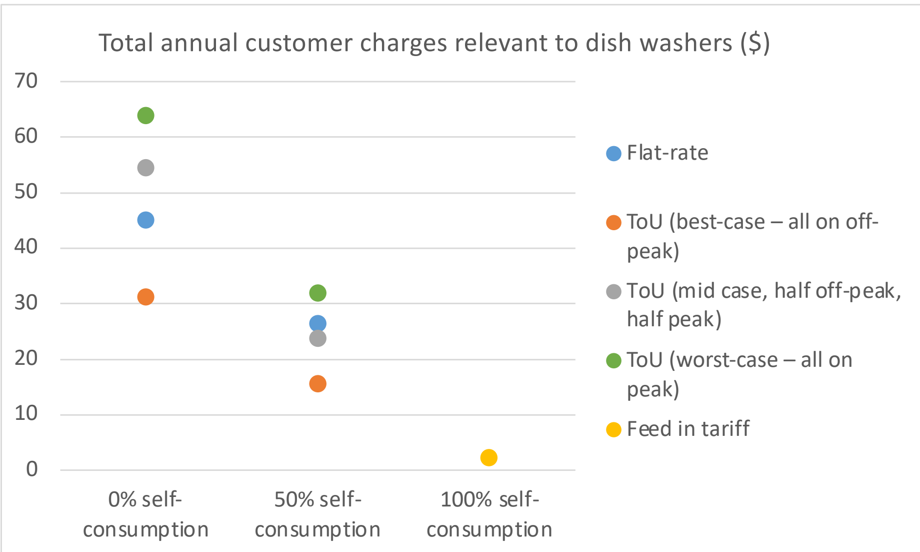

Figure 19 The potential for flexing dish washers to match onsite solar generation to reduce customer bills

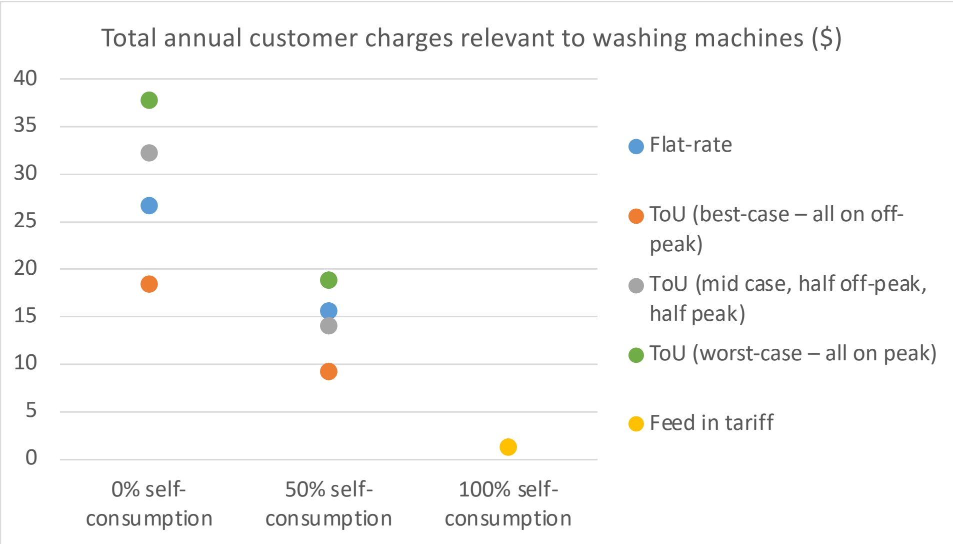

Figure 20 The potential for flexing washing machines to match onsite generation to reduce electricity bills

6.5 Potential flexible load

Figure 21 shows the potential capacity of flexible load resources at a typical household considering an average occupancy of 2.5 people.[s] The potential capacity refers to the peak load occurring in the period 3 p.m.–9 p.m. for uncontrolled loads[t]. It is noteworthy that the controlled loads are not included in this analysis because they do not occur during the defined peak period[u]. HVAC is the major source of load flexibility, while standard resistive hot water system offers a greater potential than heat pump hot water system.

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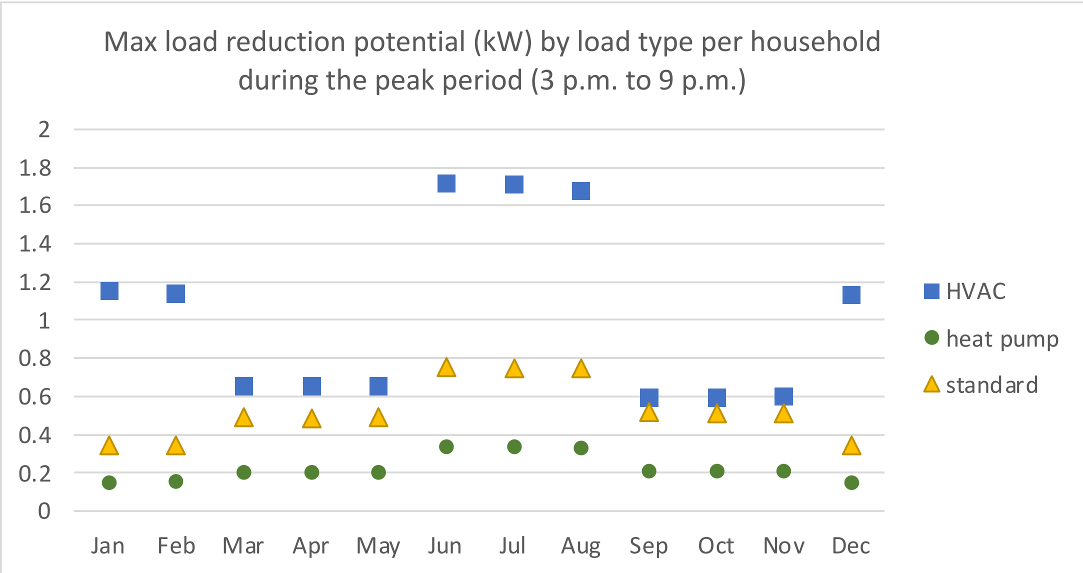
[s] Note that the flexibility potential of customers with and without solar are not distinguished as the typical HVAC and hot water loads are derived across all customer types who have the relevant appliances. Accordingly, the flexible load capacities determined do not distinguish between customers with and without solar.

[t] Note that in the absence of advanced 3rd party demand response schemes, customers (particularly those without solar) would have less incentive to shift their uncontrolled loads within the off-peak period. This explains why only the loads occurring in the period 3 p.m to 9 p.m. was considered as the flexible load capacity for uncontrolled sub-loads – consistent with the study design. It should also be noted that a load shifting program that encourages customers to shift their energy consumption to off-peak hours through the use of ToU pricing may require significant changes in consumption behaviour compared to customers currently on controlled tariffs.

[u] Controlled hot water systems including controlled standard and heat pump hot water systems, as well as boosting elements of SWHs, are not suitable residential loads for supplying flexibility, as one would expect.



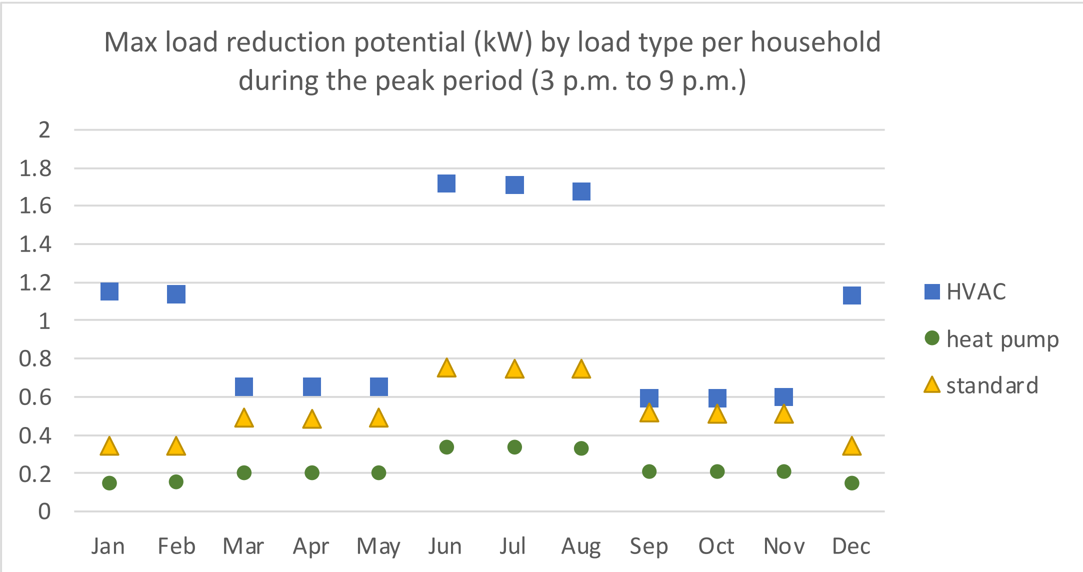


Figure 21 Potential maximum capacity of various flexible load resources at a typical household

6.5.1 Scaling up the potential flexible load to the community

To scale up the typical household-level load flexibility to the community we used the load breakdown data from Boundary 3 (Figure 22) within Heyfield. Basic data was obtained from the Ecologic audits and site inspections, with additional detail on tariffs for water heating from an analysis of onsite household-level Wattwatchers monitoring devices.

We identified 754 occupied houses in Boundary 3. The number of homes used to scale up the capacity of flexible load resources is shown in Table 6 for each type of appliance.

Table 6 Summary of load breakdown in Boundary 3

Appliance	% of homes in Boundary 3	Number of relevant homes
HVAC for heating	18%	136
HVAC for cooling	100%	754
Uncontrolled standard hot water	8%	60
Controlled standard hot water	18%	136
Uncontrolled HP	9%	68
Controlled HP	18%	136
SWH with electric boost	20%	151

Figure 22 Boundary 3 – used to scale up potential load flexibility to the community

Scaling up the HVAC load is carried out under the simplifying assumption that HVAC systems are typically used for heating during the winter months (June to August), and for cooling during the summer months (December to February). During the autumn and spring months (March to May and September to November), HVAC systems may be used for both heating and cooling, depending on the temperature. The specific use of HVAC systems during these seasons will depend on the weather conditions and temperature in a given year[v]. The weightings in Table 7 were applied to calculate the share of HVAC used for cooling and HVAC used for heating in the transition months. The load shares represent the probabilities of each purpose. For example, there is a probability of 25% that HVAC is used for heating on a day in March, and a probability of 75% for cooling.

If HVAC is used for cooling, the mean daily value of HVAC consumption can be multiplied by the number of houses that use HVAC for cooling. Around two-thirds of Victorian households (67%) have an air conditioner used for cooling[47]. Accordingly, the mean daily value of HVAC consumption is multiplied by $0.67 \times 754 = 505$ to represent houses that use HVAC for cooling. If HVAC is used for heating, the mean daily value of HVAC consumption is multiplied by the number of houses that use HVAC for heating ($n = 136$), in accordance with the share obtained from Ecologic audits, to give the approximate potential of total flexible loads on a daily basis in kWh.

Table 7 Share of HVAC load assumed for heating and cooling during the transition months

Month	Share of HVAC heating load	Share of HVAC cooling load
March	25%	75%
April	50%	50%
May	75%	25%
September	75%	20%
October	50%	50%
November	25%	75%

Figure 23 depicts the maximum load reduction potential of various hot water systems during the peak period on a daily basis in Boundary 3, with a maximum of 50 kW. The low value calculated for hot water is because

[v] The transition months between seasons are generally considered to be March, April, and May, as well as September, October, and November. During these months temperature could fluctuate from warm to cool and may require the use of HVAC systems for both heating and cooling.

this only includes uncontrolled hot water heating, as controlled water heating systems are already operated outside of peak times.

Figure 23 depicts the maximum load reduction potential of various hot water systems during the peak period on a daily basis in Boundary 3, while Figure 24 displays the maximum load reduction potential of HVAC systems. Note the different scales, with water heating a maximum of 50 kW, and HVAC 600 kW.

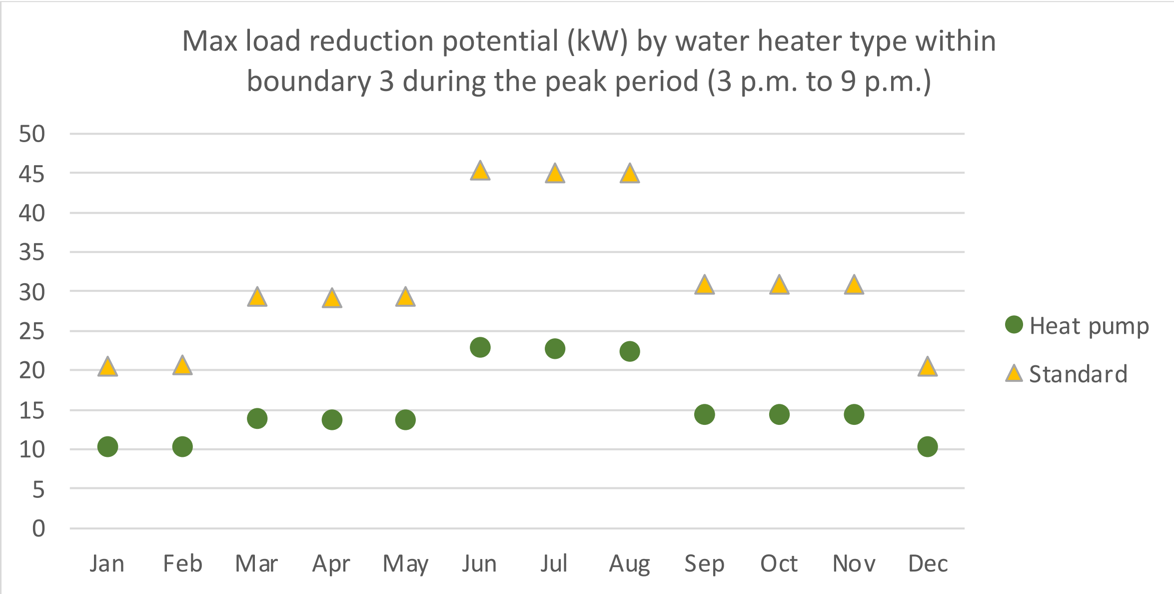


Figure 23 Maximum load reduction potential of various hot water systems in Boundary 3

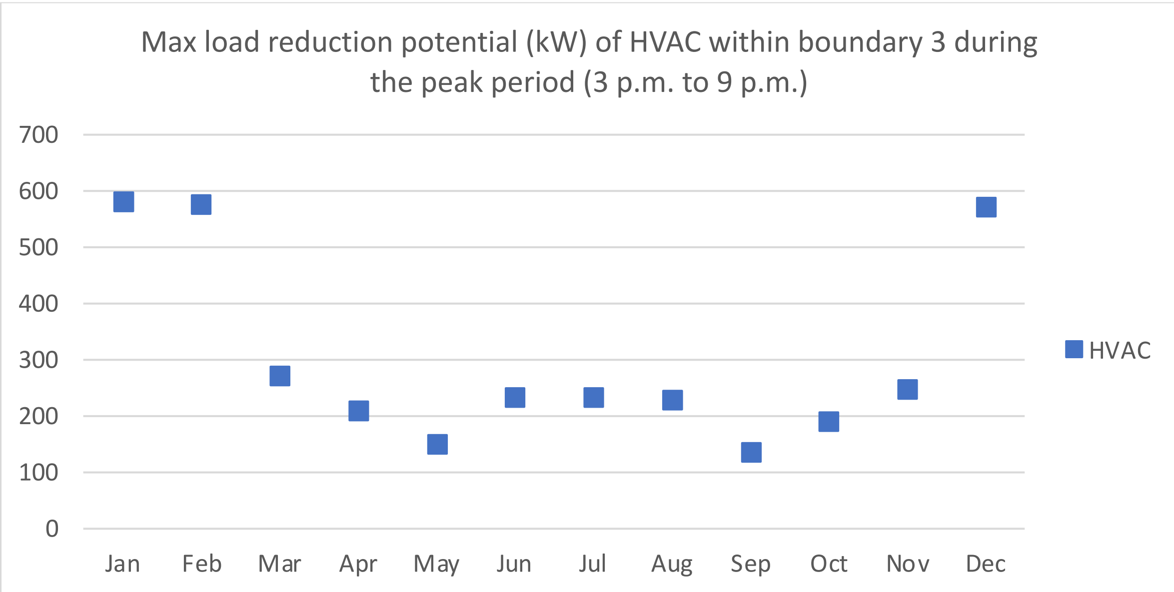


Figure 24 Maximum load reduction potential of HVAC systems in Boundary 3

6.5.2 Future water heating loads and flexibility

Controlled water heating, either standard or heat pump, has not been included in the calculation of the potential flexibility. This represents a much larger load than uncontrolled hot water, with an estimated maximum of 330 kW (winter peak). Controlled heat pumps have an estimated community wide peak of just under 70 kW and controlled standard water heating an estimated community wide peak of 288 kW[w]. It is important these loads remain flexible going forward.

[w] These add up to less than the combined peak as the standard hot water systems peak in May, while heat pump hot water heaters have their peak in June.

Approximately two thirds of residents do not currently have solar. It is likely that a significant number will become solar households because of the favourable economics or because of Heyfield's aspirations to reduce emissions and increase local energy. At that point the economics of changing to uncontrolled water heating change, so it is important to build in the ability to operate the load to coincide with generation times.

6.6 Load shape analysis

This section provides insights into the impact of the developed flexible load schedules on the relevant sub-load profiles.

6.6.1 Monthly mean daily load profiles

Figure 25 shows the uncontrolled heat pump hot water load profile before and after applying the load flex strategies specifically developed for typical customers without solar. Note the change in scale on dependent axes.

Figure 26 and

Figure 27 show the impact of load flex schedules on the uncontrolled standard hot water and HVAC load profiles of typical customers without solar (note the changes in scale between graphs). The impact of load flex strategies on the sub-load profiles of customers with solar was found to be similar.

As the figures illustrate, the greatest potential for load shifting comes from HVAC, where loads of up to approximately 2 kW on a household basis can be shifted to times when solar generation is plentiful.

Note that the negligible loads occurring at 3 p.m. and 9 p.m. are relevant to the months when the clock changes for daylight saving time.

Figure 25 Impact of load flex on uncontrolled heat pump hot water load profile: (note different scales for graphs)

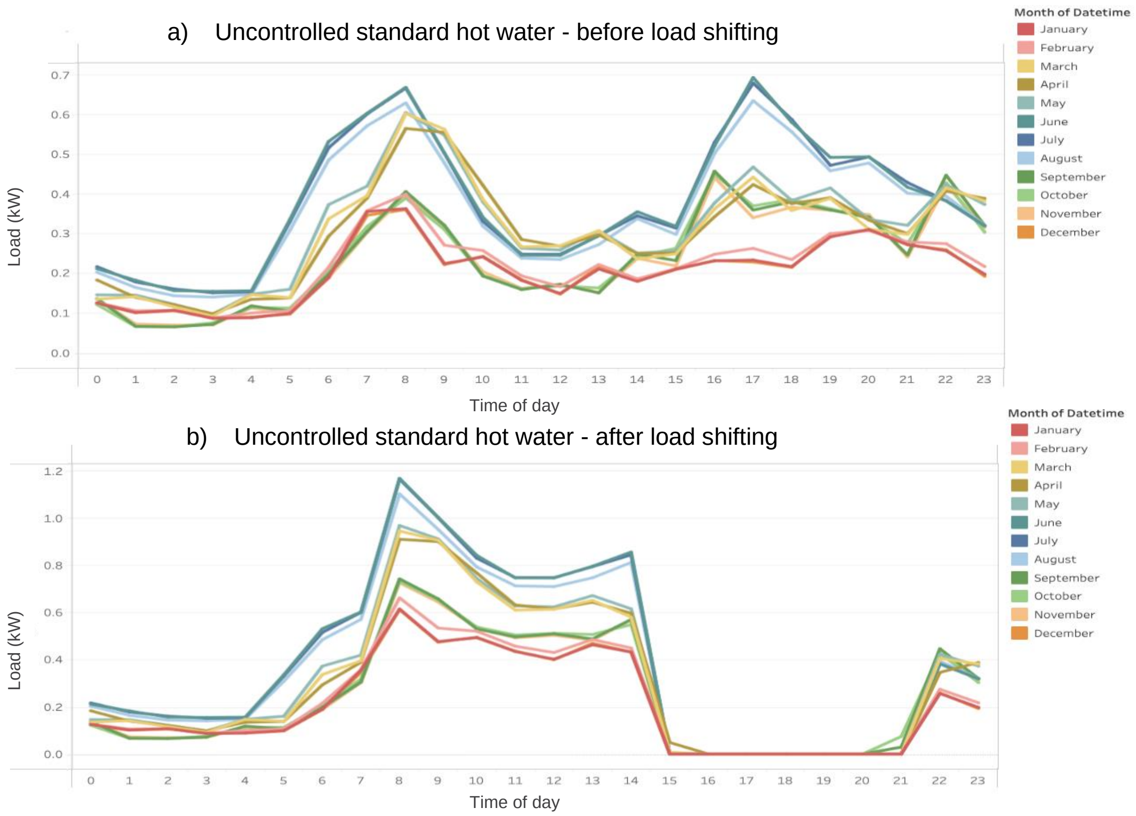


Figure 26 Impact of applying load flex on uncontrolled standard hot water load profile: (note different scales for graphs)

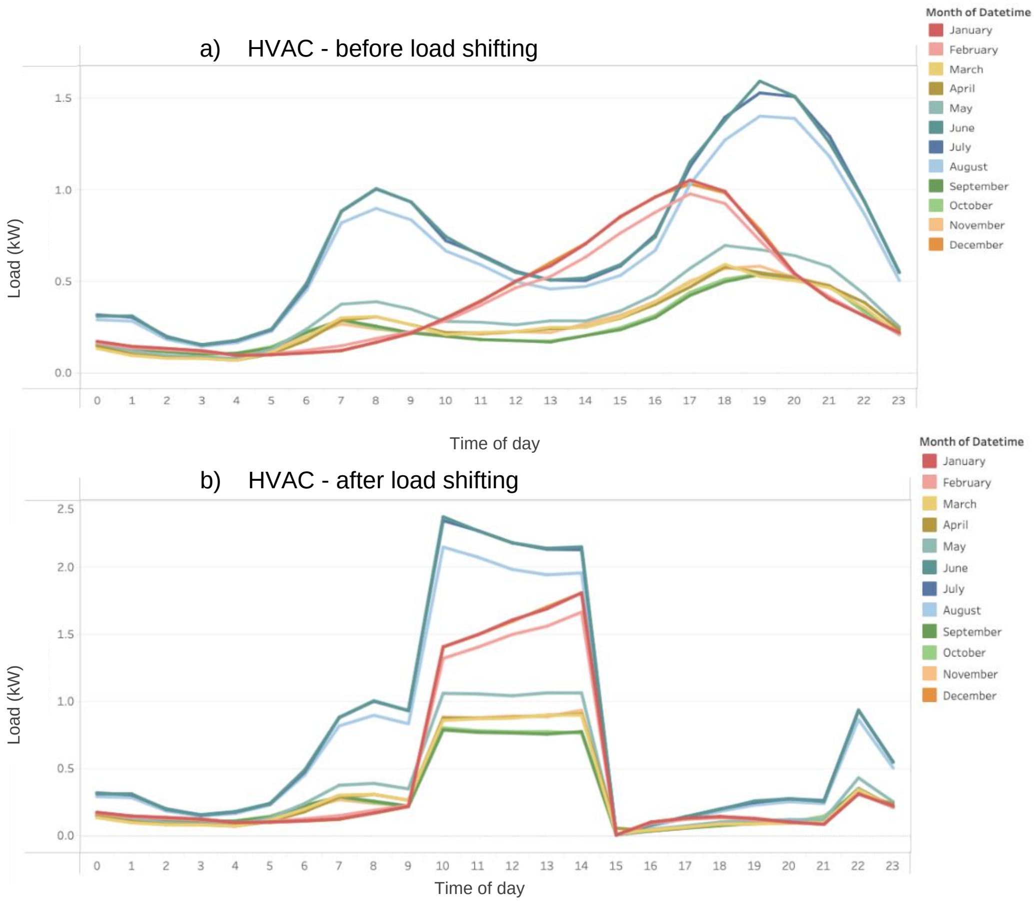


Figure 27 Impact of applying load flex on HVAC load profile: (note different scales for graphs)

6.6.2 Household-level system dynamics

For insights into the dynamics within the model at the household level, Figure 28 provides an overview of the energy balance of the case with solar, as well as the underlying load and flexed standard hot water load, for two representative days in summer, which confirms that the model adequately matches the flexible load serving times to the availability times of the onsite solar system. Note that the dark blue profile in the figure shows the net grid imports (total hourly consumption minus total hourly generation).

On both days examined, the flexible load curve is positioned perfectly underneath the relevant solar generation profile. This shows the model has intelligently responded to the availability of onsite solar generation and served the flexible load at times of solar generation. Another important insight is that, in the presence of the rooftop solar PV system, the cost-optimal solution does not entail a flat line for the flexed portion of load. Instead the flexed load is a solar generation-reflective profile which not only minimises the total customer charges, but also improves self-consumption.

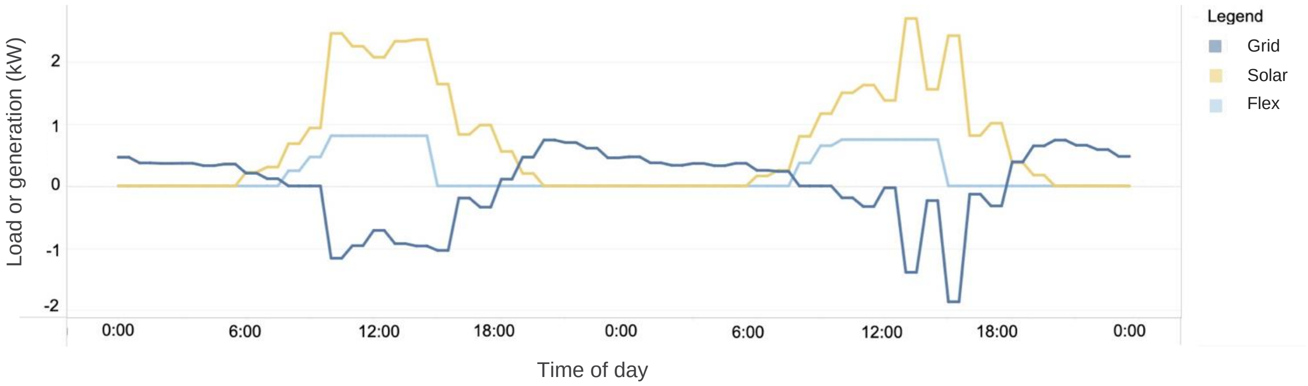


Figure 28 Household load dynamics, two representative days (solar, underlying, & flexed standard hot water)

Appendix B presents the dynamics that are taking place within the system for customers with solar for representative weeks in summer and winter for various scenarios simulated.

6.7 Limitations and barriers to uptake

The ability to make use of flexibility in residential energy consumption depends on several factors, including:

- the availability of tariff and incentive programs from utilities and other providers,
- households signing up for those programs (switching to the tariff, participating in the scheme, etc.),
- The availability of suitable energy consuming appliances and control equipment, such as electric hot water heaters and air conditioners,
- and household taking actions based on the incentives provided (shifting loads to off-peak periods, reducing peak demand, etc.),

Additionally, there are various other factors that can make it easier or harder for households to take advantage of the incentives and make changes to their energy usage, such as regulations and market conditions, the technology used for metering and controlling energy usage, social, cultural, as well as the availability and quality of information and communication channels.

The desirability of load flexibility is also influenced by working patterns, wealth, and social, cultural and behavioural factors. Households with limited resources may be highly motivated to reduce their electricity costs and might be willing to sacrifice comfort and ease for the sake of flexibility, whereas households with more resources might be less interested in providing load flexibility.

The loads to be flexed need to be in use during times when energy demand needs to be reduced or be ready to turn on when excess energy from solar power is available. Actual implementation means someone either needs to be present to turn the loads on and off, or control technologies are needed that can be scheduled or activated remotely. These can represent another barrier to uptake. Automating loads can allow for greater participation in flexibility programs, while minimising disruptions to daily routines. However, concerns about loss of control, data security, privacy, and disruptions to daily routines must be addressed.

Households may also be hesitant to use tariffs or flexibility products due to concerns around decreased comfort, additional safety risks, or a feeling of loss of autonomy. Many of these concerns are rooted in a mistrust of energy providers, especially retailers, and a general distrust of the energy market as a whole.

Another constraint on the ability to create flexibility in energy demand is related to the daily routines and social dynamics within households. The willingness and ability of households to respond to incentives can vary depending on the time of day and year, as well as depending on the type of household and whether the incentives disrupt daily routines such as mealtimes and bedtimes for children.

There are several other reasons why households may be hesitant to use alternative tariffs or other incentives to reduce and/or shift energy consumption. Studies have shown that many people do not make energy a priority in their daily lives, and that competing demands for their time and attention can make it difficult for them to engage with these programs[48]. This can be particularly challenging when load shifting or other responses require planning and coordination. Additionally, the time and effort required to research, compare, and choose a plan can be seen as too much of a hassle, and many consumers are afraid that something will go wrong if they switch providers[49]. These worries may add to a general reluctance to take risks or make changes, a preference for maintaining the status quo

People may also choose to stick to their current electricity plans and avoid alternative options, due to a variety of reasons such as fear of loss or failure, preference for immediate rewards over long-term benefits, failure to consider the opportunity cost, feeling overwhelmed by too many options, procrastination and a reluctance to deal with the inconvenience, such as the time and effort required to change plans[50]. Sometimes, a belief that actions already taken, such as purchasing a solar system or energy-efficient appliances, are enough to meet energy-saving goals, can also discourage engagement. These biases and constraints can result in a disconnect between an individual’s economic or environmental goals and their everyday energy behaviours – a phenomenon referred to as cognitive dissonance[51].

A review of the relevant literature suggests that loads such as dishwashing, clothes washing and drying are considered more discretionary than HVAC and electric water heating loads, and are therefore more likely to be responsive to tariffs[52]. They are also more commonly used to increase the use of self-generated solar power[53]. However, the results from this study corroborate the previous findings that the impact of these loads on overall flexibility is relatively small and there seems to be a mismatch between their potential and availability to provide flexibility.

7 Discussion and conclusions

This study included two domestic loads with high potential for flexibility:

1. Air conditioning systems: these consume a significant amount of energy and have high peak loads, and shifting their usage to off-peak periods can have a major impact on overall electricity demand during peak times.
2. Electric water heaters: are another major source of energy demand, and the ability to control their usage can also have a significant impact on peak demand.

The impact of unlocking the flexibility potential of HVAC systems and various types of electric water heating systems – standard resistive, heat pump hot water, and electrically-boosted SWH – on customers' electricity bills was evaluated by developing effective load shifting flexibility strategies.

The findings from this study suggest that there is significant potential for customer savings from flexible loads at the domestic level. Peak load reductions were also available at the community level. Specifically, for Boundary 3 within Heyfield, a maximum load reduction potential of 50 kW was calculated for standard resistive water heaters, and a maximum of 600 kW for HVAC loads.

Implementing load flexibility to shift load to hours when solar generation is plentiful not only reduces energy costs but also reduces carbon emissions. For customers with solar, it reduces the need to import electricity from the grid, and for customers without solar, it means taking advantage of excess solar energy generated by their neighbours. This helps to promote a more sustainable energy system and support the transition to a low-carbon economy.

7.1 What gives good returns?

It was found that HVAC systems and standard resistive hot water systems are the major sources of economic load flexibility at the domestic level. Potential annual savings for different customer groups were estimated at between $83 and $226 (HVAC) – equating to between a 12% and 31% HVAC bill reduction – and between $59 and $151 (standard water heating) for different customer groups – equating to between 15% and 25% standard water heating bill reduction.

We have not assumed any enablement technology costs for HVAC, as it is assumed that load shifting would be achieved via the time clocks built into the HVAC systems. We have included a cost of $1,425 for resistive hot water diverters for customer with solar, and a cost of $325 for hot water timers for customers without solar. The savings would, of course, be more significant for standard water heating if we did not factor in the costs associated with capital-intensive solar diverters and relied on timers.

According to the results of this study, houses without solar that use HVAC as their main heating source would benefit the most from implementing load shifting (combined with switching to a ToU tariff), and could save 22% of their HVAC bill, estimated here as $192. For customers with solar, the savings range from 12% and 31% of the HVAC bill, estimated here as saving between $83 and $226. Also, houses with solar have the added benefit of improved self-consumption. This means that they can generate and use their own power on site, reducing their reliance on the grid and potentially saving money on energy costs.

Wattwatchers monitoring devices can be used to track the amount of energy produced by the solar panels, as well as energy consumed by HVAC and water heating loads, allowing homeowners to make informed decisions about their energy usage if they have a device installed.

7.2 Risks

Switching from the flat-rate to the ToU tariff: while changing tariff can offer cost savings for those who are able to use energy during off-peak times, it can result in higher costs for those who are not able to adjust their energy usage to align with the lower rates. Figure 29 shows the impact of switching from a flat tariff to a time of use tariff without implementing load flexibility. The results suggest even without load flexibility, customers both with and without solar will experience relatively small changes in their bills. Solar customers may see bills get somewhat worse (between 2% and 5%), while customers without solar should see a slight improvement. Of course, customers with solar are more likely to already be on time of use tariffs, in which case there is no risk.

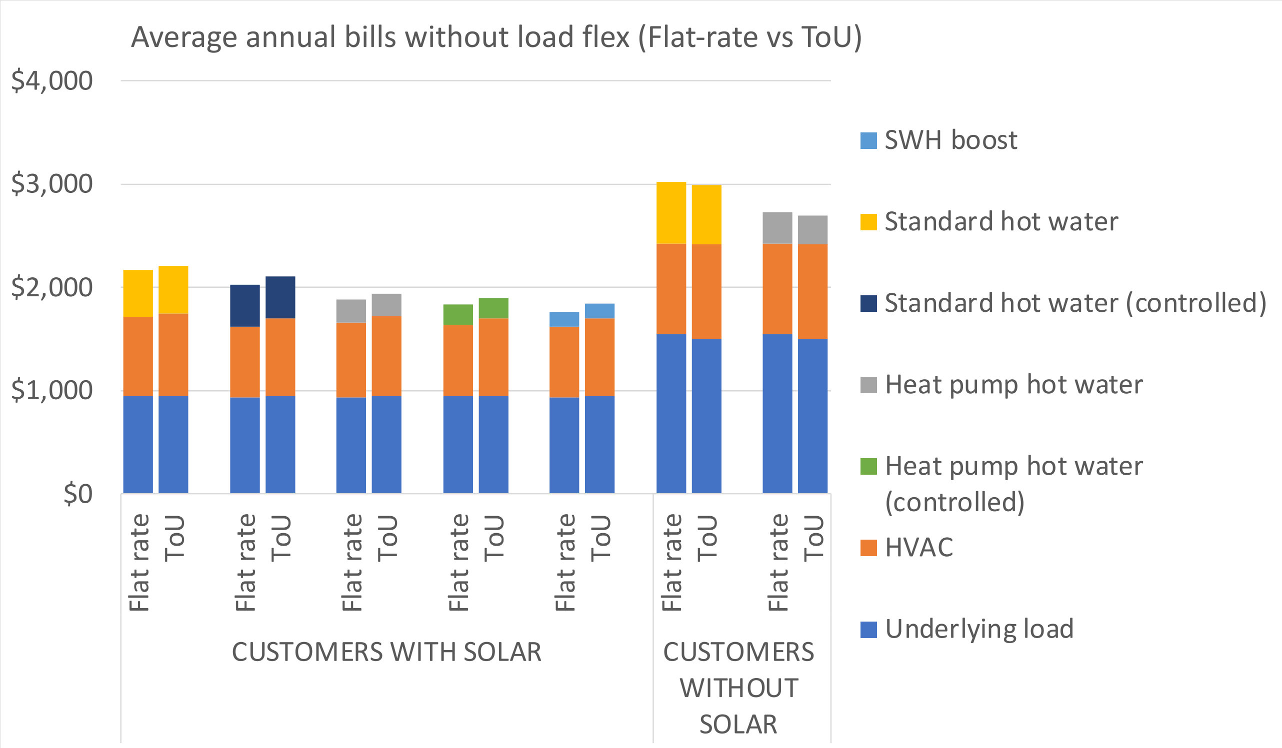


Figure 29 The impact of switching from flat-rate to ToU tariffs on annual customer bills

Risk of non-realisation of savings with load flexibility: there is always a chance that savings are not realised, despite the assumed low or zero capital costs for enabling load flexibility. This is particularly relevant for resistive hot water systems for customers with solar, which entails a cost of $1,425 for hot water diverters. It may be possible to flex this load without this relatively high investment, by manually turning on the hot water system when solar generation is plentiful. The process typically involves monitoring solar generation levels and using a significantly cheaper manual switch or timer to turn on the hot water system when the solar generation is sufficient and turn it off when it is not. It is important to note that this method may not be as effective as utilising solar diverters which are able to intelligently track solar generation and automatically adjust the hot water usage accordingly, which can lead to more significant energy savings and cost-effectiveness in the long run. Therefore, proper management and execution of load shifting and flexibility strategies, as well as investigation of cheaper control technologies, is crucial to realise the expected energy cost savings.

Load flexibility and shifting load to off-peak hours: While this can help reduce energy costs, it also poses a risk of homes not being warm or cool enough if the energy usage is not properly timed or managed. However, improving the building fabric and ventilation strategies mitigates this risk and reduces overall energy consumption. This could include adding insulation, upgrading windows, or sealing air leaks (for heating load), or improving air flow (for cooling load). Improving the building's fabric not only reduces the risk of savings not eventuating, it can improve thermal comfort, improve energy efficiency, reduce energy costs, and improve indoor air quality.

7.3 Implementation options

Set built-in timers: This is a low-cost option that can be easily implemented by householders with the proper communication and training. This option allows the load flexibility to be programmed based on the household's energy consumption patterns and can be easily adjusted as needed.

Demand Response Enabling Devices: While DREDs may offer additional benefits in the future, DRED-enabled load flexibility programs are not currently available within AusNet service area. It is important to keep an eye on the development of this technology and evaluate if it is a viable and worthwhile option in the future. However, according to a recent discussion with AusNet representatives, the implementation of DREDs is not a priority in the short to medium term at least.

7.4 Caveats

It is important to keep in mind that load flexibility strategies may have general limitations and may not be applicable to all households. Flexibility strategies are not relevant for households that do not have flexible resources, without access to off-peak electricity tariffs, or without the ability to shift energy consumption.

Additionally, the potential benefits may differ from those estimated here. Potential savings are relative to current spending, so households that have low HVAC or water heating related spending will have smaller benefits from implementing load flexibility. For example, if you currently spend only $200 per year on consumption for HVAC, reducing the HVAC element of your bill by 25% would save you $50 per year, rather than the $83-$226 estimated in this analysis.

For customers with solar the modelled savings come in part from using their own generation to meet the loads that are shifted, so it is important to consider the match between energy consumption and generation. It is important to note that we have assumed the use of dynamic control of flexible resources for customers with solar, such as the tracking of solar generation, to achieve the best-case results. This may not be feasible or practical for all households, and the actual savings may be lower if these assumptions are not met. Therefore, it is important to carefully evaluate the potential benefits and limitations of load flexibility strategies for each individual household.

Proper communication and monitoring are crucial for the effective implementation of load flexibility strategies.

7.5 Recommendations

Based on the analyses and findings presented, implementing effective load flexibility strategies could reduce energy costs for some residents, increase the proportion of locally consumed solar, and reduce the town's peak load. The following set of recommendations are provided for *Heyfield MyTown energy to consider:*

1. *Consider running a pilot load flexibility programme:* while this could be standalone, it is likely to produce better outcomes as part of a package of on-site measures.
2. *Prioritise load flexibility for HVAC systems where applicable:* as this is the main source of cost savings. Note that this is only likely to be effective where there exists sufficient thermal mass to store daytime heating in the building fabric. Flexing HVAC can be low cost, as it simply requires programming built-in timers in order to align with off-peak electricity tariffs.
3. *Consider combining with advice on fabric improvements:* the effectiveness of flexing HVAC is likely to improve if combined with investing in complementary technologies such as insulation and air-tightness to enhance energy efficiency and comfort.
4. *Consider the impact of load flexibility on thermal comfort:* shifting the load means you are pre-cooling or pre-heating the home, so people should consider how this will work in their particular circumstances.
5. *Evaluate the potential benefits and limitations of load flexibility strategies for each individual household:* this includes considering factors such as the availability of flexible resources, the level of solar generation if applicable, the current tariff, and current spending on HVAC to determine the potential savings from load flexibility. We advise using a simple calculator to assess the benefits.
6. *Evaluate the impact of the expiration of premium feed-in tariffs on solar customers:* as of November 2024, the premium feed-in tariff rate will expire and be reduced from $0.60/kWh to $0.05/kWh. This will increase electricity bills for solar customers and make it much less financially beneficial to export electricity to the grid. Implementing load flexibility strategies to maximise the use of their own generated electricity is the most effective way to mitigate the bill increase.

7. *Provide education and training to households:* on how to effectively implement load flexibility strategies and how to use the tools available to them, such as built-in timers and home energy management systems. This includes training on the different energy tariffs and how to understand electricity bills, how to program and adjust timers for HVAC, and how to monitor and track energy usage. The education and training can be provided through various means, such as online tutorials, brochures, workshops, and webinars. Providing education and support will increasing the likelihood of successful implementation and achieving the desired energy cost savings.
8. *Encourage the use of energy monitoring and management systems:* for example, Wattwatchers monitoring devices, to monitor energy usage and make load flexibility strategies more effective. And help customers reduce overall energy use. Monitoring devices can provide households with detailed, real-time information about their energy usage, including the breakdown of usage by appliance. This could give households a better understanding of their energy usage and enable more informed decisions about load flexibility strategies, which can lead to greater energy cost savings. Device information can be used to identify patterns of energy consumption and adjust load flexibility strategies accordingly. They can also provide alerts when energy usage exceeds a certain threshold, allowing households to take corrective action in real-time.

Appendix A Outcomes for customers currently on ToU

This Appendix presents the modelling results for the customers currently on the ToU tariff.

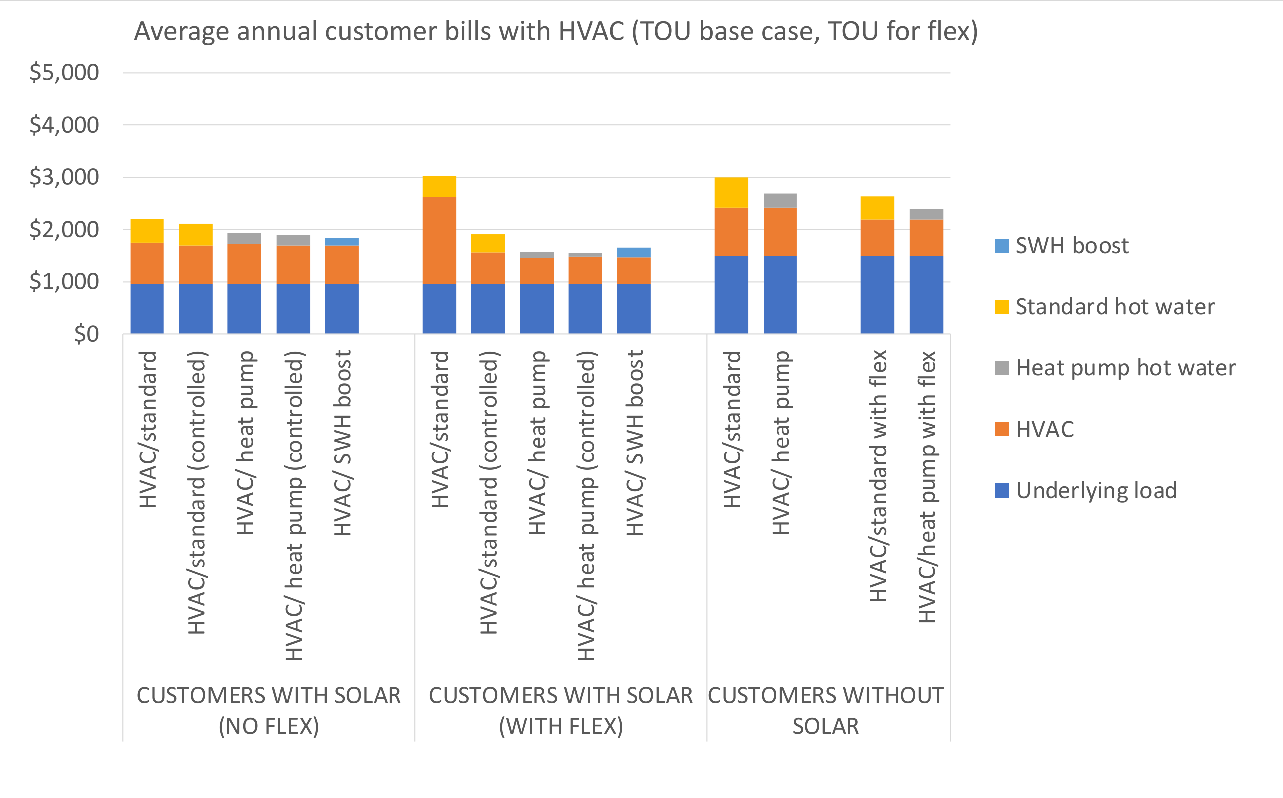


Figure 30 Average annual bills with HVAC and electric water heating – customers currently on ToU

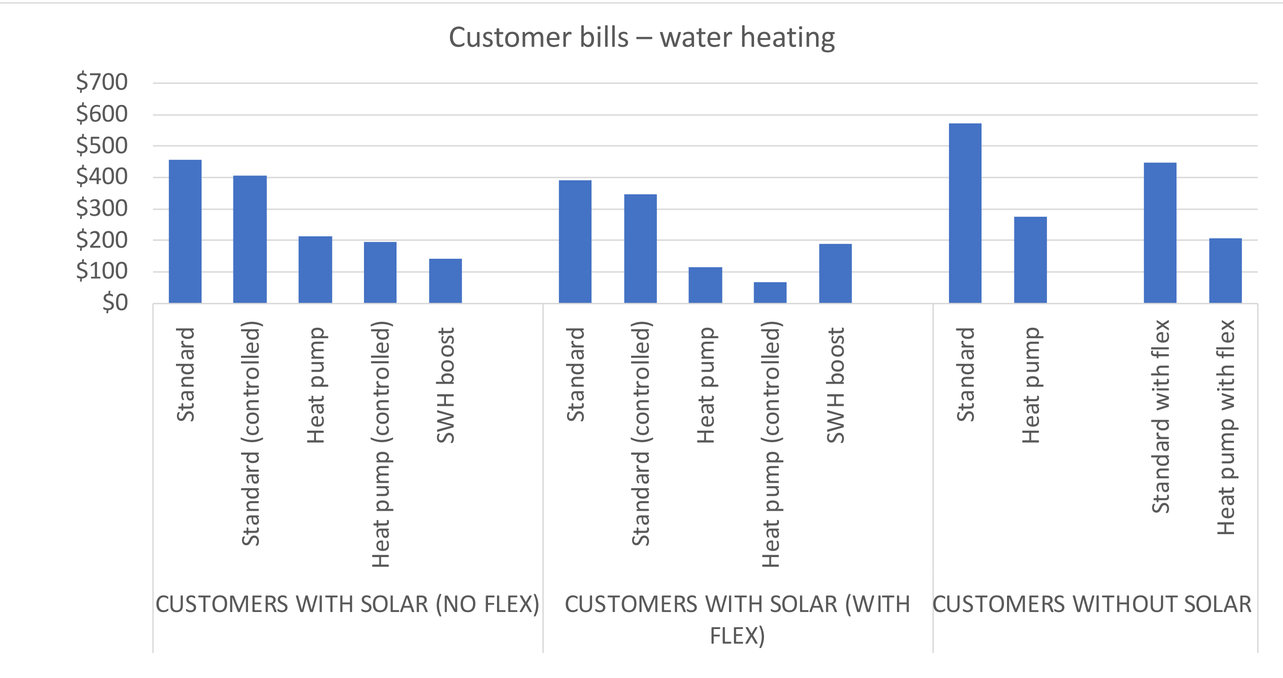


Figure 31 Average annual bill for water heating – customers currently on ToU

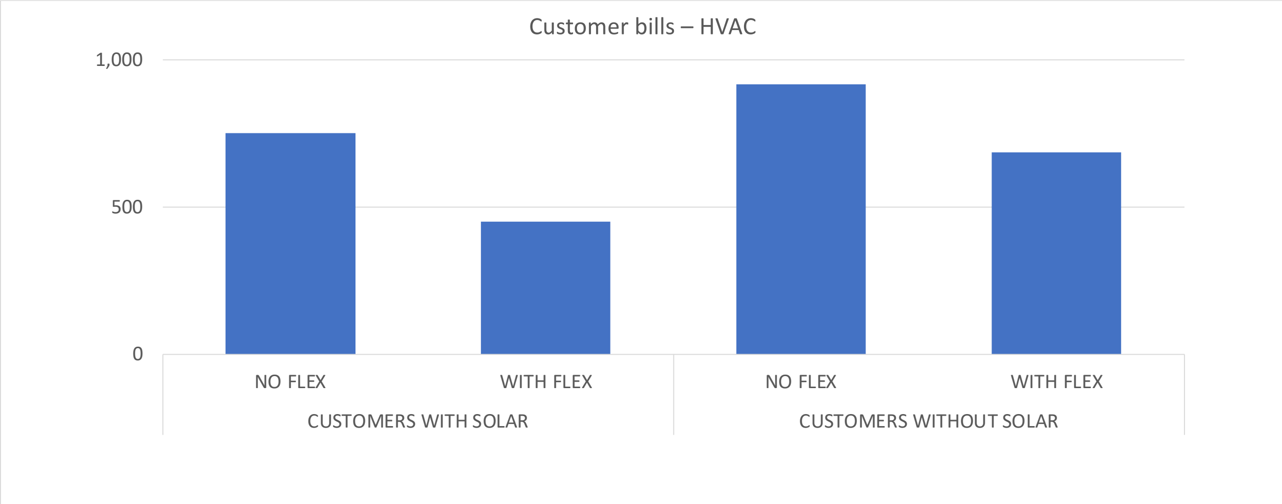


Figure 32 Average annual bill for HVAC – customers currently on ToU

Appendix B Additional modelling results – load dynamics

This Appendix presents the dynamics that are taking place within the system for customers with solar and currently on the flat-rate tariff for representative weeks in summer and winter for various scenarios.

Underlying load (representing customers with gas/ wood space heating and gas water heating)

Figure 33 shows the dynamics that are taking place within the model in terms of energy balance for a week in winter.

Figure 33 System dynamics for underlying load for a representative winter week

Underlying load + HVAC (with and without load flex)

Figure 34 shows the dynamics that are taking place within the model in terms of energy balance for a week in summer and winter.

(a)

(b)

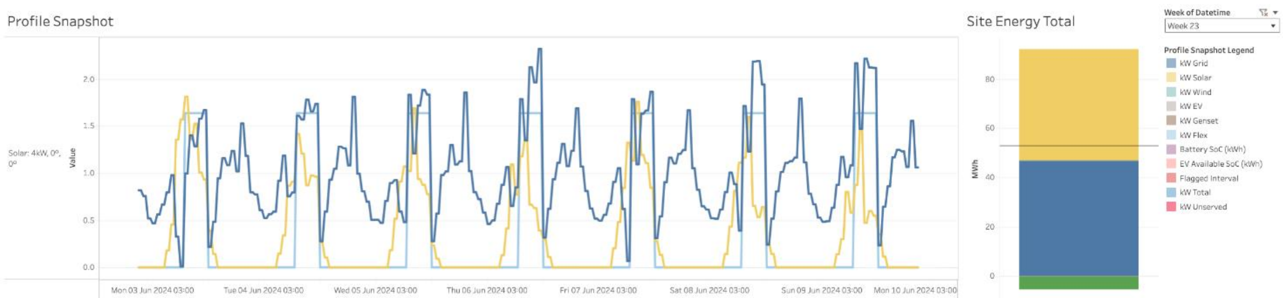


Figure 34 System dynamics for underlying load & HVAC for (a) summer week and (b) winter week

Underlying load + Hot water sub-load (with and without load flex)

Day-rate (uncontrolled) heat pump hot water system

Figure 35 shows the dynamics that are taking place within the model in terms of energy balance for a week in winter.

Figure 35 System dynamics for underlying load & uncontrolled heat pump hot water (winter week)

Off-peak night (controlled) heat pump hot water system

Figure 36 shows the dynamics that are taking place within the model in terms of energy balance for a week in summer and winter.

(a)

(b)

Figure 36 System dynamics for underlying load & controlled heat pump hot water: (a) summer & (b) winter week

Off-peak night (controlled) standard electric element (resistive) hot water system

Figure 37 shows the dynamics that are taking place within the model in terms of energy balance for a week in summer and winter.

(a)

(b)

Figure 37 System dynamics for underlying load & controlled standard hot water, (a) summer & (b) winter week

Solar hot water system with off-peak night (controlled) electric boost

Figure 38 shows the dynamics that are taking place within the model in terms of energy balance for a week in summer and winter.

(a)

(b)

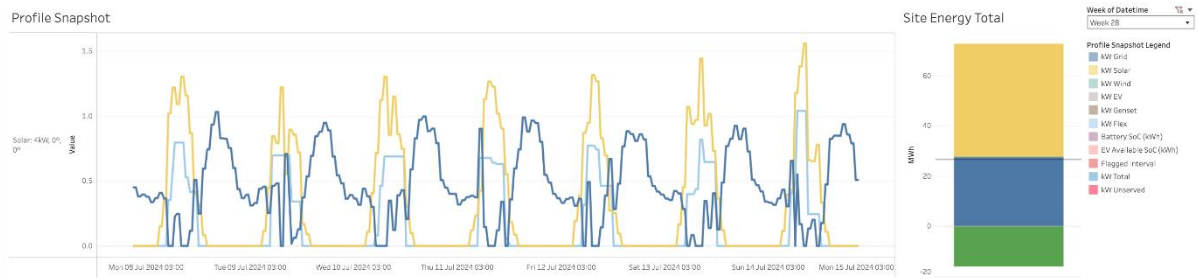


Figure 38 System dynamics for underlying load & controlled solar boost hot water, (a) summer & (b) winter

Underlying load + Hot water sub-load + HVAC sub-load (with and without load flex)

Day-rate (uncontrolled) heat pump hot water system

Figure 39 shows the dynamics that are taking place within the model in terms of energy balance for a week in summer.

Figure 39 System dynamics for underlying load, HVAC, & uncontrolled heat pump hot water (summer week)

Off-peak night (controlled) heat pump hot water system

Figure 40 shows the dynamics that are taking place within the model in terms of energy balance for a week in summer.

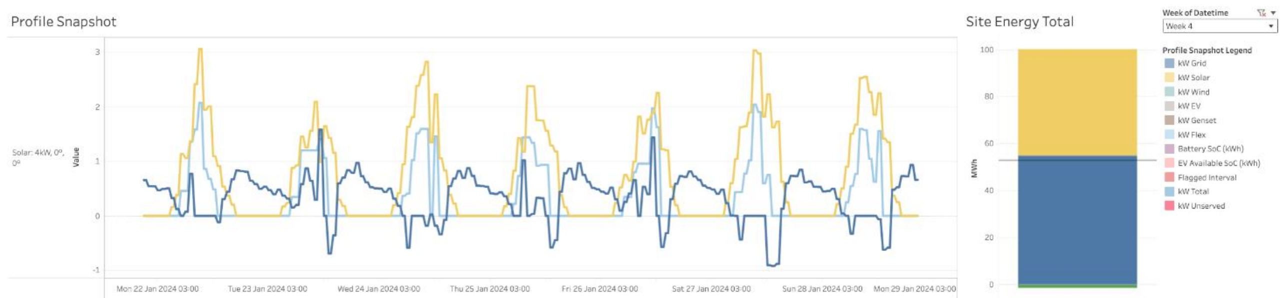


Figure 40 System dynamics for underlying load, HVAC, & controlled heat pump hot water (summer week)

Off-peak night (controlled) standard electric element (resistive) hot water system

Figure 41 shows the dynamics that are taking place in terms of energy balance for a week in summer.

Figure 41 System dynamics with underlying load, HVAC,& controlled standard hot water (summer week)

Solar hot water system with off-peak night (controlled) electric boost

Figure 42 shows the dynamics taking place in terms of energy balance for a week in summer.

Figure 42 System dynamics for underlying load, HVAC, & controlled solar boost hot water (summer week)

Appendix C Enabling technologies for load flexibility – additional information

An examination of technology providers in Australia was conducted to gather information and determine the costs associated with implementation needed for this analysis. This included phone calls with relevant technology providers, visiting their websites, and gathering any additional information deemed necessary to complete the analysis. This approach ensured a good understanding of the market, and its offerings was obtained, providing a solid foundation for the cost analysis.

Table 8 and Table 9 provide a comparison of various timer and solar diverter brands for hot water control, respectively.

Table *10* presents a comparison of various energy management systems available on the market[x].

Table 8 Comparison of timer brands for hot water control

Name	Company	Sub-loads controlled	Capital cost	Installation cost
Hager hot water timer[1]	Hager	Hot water	$125	$100 - $200
Intermatic 318352 electric water heater timer[2]	Intermatic	Hot water, heat pump	$140	$100 - $200
GE Timer Switch[3]	GE	Hot water, heavy loads	$430	$100 - $200
Suraielec WiFi Timer[4]	SURAIELEC	Hot water	$190	$100 - $200
GE Mechanical Time Switch[5]	GE	Hot water	$140 - $160	$100 - $200
Honeywell ST9100 timer[6]	Honeywell	Hot water	$170 - $250	$100 - $200
Intermatic hot water timer[7]	Intermatic	Hot water	$140 - $160	$100 - $200
Heavy duty switch[8]	AEOTEC	Heavy loads up to 40A	$170	$100 - $200

[1] https://supplyinstalled.com.au/Hager-Hot-Water-Timer
[2] https://www.ebay.com/itm/123858695134
[3] https://www.amazon.com.au/GE-Heavy-Duty-Resistant-Universal-46537/dp/B07TVKSDD4/ref=d_pd_vtp_sccl_2_2/355-6529489-5353320?pd_rd_w=gQRm5&content-id=amzn1.sym.6c5371fd-e430-44b8-a1bd-99d66b7c7085&pf_rd_p=6c5371fd-e430-44b8-a1bd-99d66b7c7085&pf_rd_r=MYPWRH4E514GZMJKADW4&pd_rd_wg=0Qf6u&pd_rd_r=cbe36f67-3141-4a2d-b1e7-ccc6e9015d4a&pd_rd_i=B07TVKSDD4&psc=1
[4] https://www.amazon.com.au/Suraielec-Controller-Powerful-Electrical-Appliances/dp/B08VS7SRHN/ref=d_pd_sbs_sccl_1_1/355-6529489-5353320?pd_rd_w=hKqfE&content-id=amzn1.sym.118da4f1-91dc-4b99-99f1-19f25add64eb&pf_rd_p=118da4f1-91dc-4b99-99f1-19f25add64eb&pf_rd_r=S7TFDA42E1HERMMXZBEY&pd_rd_wg=ET13d&pd_rd_r=fc775b2d-1bc7-4f3e-a00f-5739fbc02b88&pd_rd_i=B08VS7SRHN&psc=1
[5] https://www.amazon.com/GE-Heavy-Duty-Mechanical-Resistant-46536/dp/B00CYVBWYG/ref=sr_1_3?keywords=hot%2Bwater%2Bheater%2Btimer&qid=1672092860&sr=8-3&th=1
[6] https://www.ebay.com/itm/234413245522
[7] https://www.amazon.com/Intermatic-WH21-Water-Heater-Timer/dp/B00002N5FP
[8] https://smarthomedirect.com.au/product/aeotec-z-wave-heavy-duty-switch/

[x] The cost and availability information presented in this report is accurate as of the date of its composition. We do not assume responsibility for any changes in cost and availability, as these are subject to fluctuations beyond our control. Also note that the cost of retrofitting is dependent on the specific household in which the system is being installed. The estimated costs presented here are for reference purposes only.

Table 9 Comparison of solar diverter brands for hot water control

Name	Company	Sub-loads controlled	Capital cost	Installation cost
Catchpower - single phase power diverter[1]	Rainbow Power Company	Standard resistive hot water system	$1,000	$200 - $600
Sunmate 2.0 AWS[2]	AWS	As above	$850 - $900	$200 - $600
Power Diverter model 3 outdoor with off peak relay[3]	Power Diverter	As above	$900	$200 - $600
Power diverter indoor without off peak relay[4]	Power Diverter	As above	$730	$200 - $600
Power diverter - outdoor with off peak relay[5]	Power Diverter	As above	$770	$200 - $600
Paladin solar diverter[6]	Paladin	As above	$990	$200 - $600
Myenergi eddi[7]	myenergi	As above	$900 with an additional $180 for the energy monitoring device	$200 - $600
Immursun solar diverter[8]	Immursun	As above	$850 - $900 with an additional $300 for the energy monitoring device	$200 - $600
Solaredge smart hot water immersion heater control[9]	Solar edge	As above	$1,000	$200 - $600
Fronius Ohmpilot[10]	Fronius	As above	$1,400	$200 - $600

[1] https://www.rpc.com.au/shop/catchpower-green-catch-single-phase-power-diverter-p-4881.html

[2] https://www.australianwindandsolar.com/product-page/aws-sunmate-

[3] https://www.powerdiverter.com.au/online-store

[4] https://www.powerdiverter.com.au/online-store

[5] https://www.powerdiverter.com.au/online-store

[6] https://www.paladinsolarcontroller.com.au/shop/

[7] https://myenergi.com.au/product/eddi/

[8] https://www.immersun.co.uk/

[9] https://www.solaredge.com/us/products/smart-energy/solaredge-home-hot-water-controller

[10] https://www.fronius.com/en/solar-energy/installers-partners/technical-data/all-products/solutions/fronius-solution-for-heat-generation/fronius-ohmpilot/fronius-ohmpilot

Table 10 Comparison of various energy management systems

Name	Company	Sub-loads controlled	Capital cost	Installation cost	Remarks
Home Energy Management System (HEMS)[1]	Solahart & Rheem	Hot water HVAC, other discretionary loads	$600 (energy monitoring device alone)	$200 - $600	Usually bought with Powerstore heat pump costing $4,000
Ubi Energy Management Platform[2]	Mondo	As above	$1,400 - $1,600	$200 - $600	-
Ember Pulse[3]	Beat Energy	As above	$1,000 – 1,200	$200 - $600	-
Add contactor to Wattwatchers monitoring device with switching	WattWatchers	Hot water	$20 plus installation cost	$350 per site	Out of the 141 devices installed in Heyfield, only 27 have switching capability
New Wattwatcher Auditor A6M+3SW + contactor	WattWatchers	Hot water	$335 per site	$350 for installation per site	

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[21] https://www.ecobee.com/en-us/

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