Australian National University

ANU Centre for Energy Systems

Renewable Renters – Load Shifting Solutions for Student Renters

Empowering student renters to be included in Australia's energy transition

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2 ABSTRACT

Student renters face challenges accessing the same range of renewable energy technologies that are available to homeowners, such as rooftop solar and batteries.

Rooftop solar has exploded in popularity in Australia, adopted by around 1/3 of households nationwide [1] The National Energy Market, Australia's main grid, saw renewables make up to 36% of all energy generation in 2024 [2]

This report aims to identify solutions that student renters in the ACT can use to shift their daily electricity demand to times when renewable penetration is high, for the purpose of empowering this demographic to be able to participate in the energy transition.

Thirteen solutions were shortlisted for analysis for the purpose of identifying the 4 most effective solutions. The analysis process was conducted to understand the extent of the economic, environmental, social, technical and policy impacts of each solution. Economic analysis includes the Net Present Value from each solution, environmental analysis includes a Life Cycle Assessment to identify the material inputs for each solution and the environmental impacts of sourcing each one, social analysis involved interviews with 2 subject matter experts to gain an understanding of the socio-cultural barriers that student renters face, technical analysis looked at the performance of each solution in shifting energy in kWh/year, and policy analysis includes a subject matter expert interview and looking at each final solution to identify the most appropriate policy that can be implemented to drive uptake.

The 4 most effective solutions were found to be delay start appliances, power point timers, power banks, and an insulation package (including door snakes, thermal curtains, room dividers and temporary double glazing). These were particularly favourable due to their relative affordability, and temporary/moveable nature which means they can be reused at another rental if the tenant relocates.

The economic analysis found insulation packages are deemed to provide the largest economic payback to renters over their lifetime and therefore are the most highly recommended. This is followed by delay start appliances and then power point timers. Power banks produced a negative result and thus are not recommended as an economic investment for renters as over the course of their lifetime the initial capital investment is never returned through energy savings.

The technical analysis found that maximising energy savings relies heavily on consistent user adoption, which is particularly challenging in student households with variable schedules and low incomes. Solutions are most effective when they require minimal effort or are automated. Power point timers could shift 755 kWh/year, power banks 29 kWh/year, insulation package 1,837 kWh/year, and delay start appliances 1,511 kWh/year.

The environmental analysis found power point timers and power banks to have lesser impacts in the fossil fuel depletion and global warming impact categories. Delay start appliances have the greatest impacts of all products assessed. Of the products comprising the insulation suite, the product with the greatest impact—being the thermal curtains—induces less than 30% of the fossil fuel depletion and global warming of the maximum impacts observed by the washing machine.

The policy analysis found that 3 of the 4 solutions would benefit from a policy. Specifically, the timers and power banks could be procured then distributed to student renters free of charge at a central distribution point due to their cheap and portable nature, and the insulation package could be procured and delivered to homes for free to remove the barrier to entry of transporting the bulky materials.

The social analysis found 3 key themes to the socio-cultural barriers faced by student renters: Theme 1 - People's motivations to engage in household energy practises differ depending on their primary concern, which is ultimately influenced by their capacity; Theme 2 - Simple solutions and the Landlord power dynamic; and Theme 3 - Communication, engagement and capacity.

3 INTRODUCTION

In 2023, 30% of Canberra households had rooftop solar systems [3], and it is predicted to increase into the future as technology improves and decarbonisation strategies accelerate [4]. This allows homeowners to access the flexibility benefit of renewable energy technology, giving them control of their energy consumption and helping to reduce their electricity bill from a lower reliance on the National Electricity Market (NEM). This also contributes to a reduction of Greenhouse Gas (GHG) emissions from lower overall national demand and greater renewable energy penetration. Furthermore, since December 2023 new homes in the Australian Capital Territory (ACT) have been banned from having a gas connection [5], so all appliances must be electric. There are also strong incentives for uptake of energy efficient products like reverse cycle air conditioners and heat pump water storage tanks. However, renters do not have the authorisation to make permanent changes to their house (such as solar panels and battery storage) without consulting and getting approval from the landlord, and they don't have the financial incentive to invest in changes to a house they do not own. Therefore they do not have the same access to these renewable energy solutions available to landlords.

One of these sub-groups of renters in the ACT are university students. In 2021, there were approximately 36,000 university students in the ACT, and at Australian National University (ANU) alone, 68% are interstate or international students, commonly requiring rental properties [6] [7].

Student renters can attribute more of their energy consumption to renewable sources by concentrating their energy demand to periods of the day when the NEM has high penetration of renewably sourced electricity. These periods are typically in the middle of the day (with electricity from solar panel farms and distributed rooftop solar) and the middle of the night (with electricity from wind farms and hydropower) and are considered 'off peak' because of the comparatively low demand but high supply. Particularly on sunny days, there can be an excess of generated renewable electricity, which may be wasted because the demand and supply curves are not aligned. In the peak periods (morning and evening), the proportion of electricity generated from the combustion of fossil fuels is the highest in order to meet the 'peak' in electricity demand across the grid at those times [8].

A *load or demand shifting solution* is a product, system or behaviour that enables the transfer of electricity demand to the off-peak periods in the middle of the day and night. The net daily electricity consumption remains the same, however the demand profile can be adjusted to align better with the renewable energy consumption profile. There are already several solutions available to renters to shift their energy demand towards off-peak periods. This report identifies load shifting solutions and analyses them against a set of criteria and requirements to analyse their suitability for ACT student renters. This report will then provide a shortlist of recommended solutions that are most suitable for student renters, discusses their strengths and weaknesses, and outlines policy options for how uptake of these solutions can be increased.

There are many benefits that load shifting can bring to student renters. It can help them access cheaper daytime electricity from the NEM when using time-of-use tariffs and decrease their GHG emissions from their electricity usage. Shifting demand from peak times to the middle of the day also uses excess solar being produced by the grid particularly on sunny days and flattens the overall demand curve throughout the day, reducing the need for fossil fuel-derived electricity generation and stabilises grid supply and demand profiles. Overall, load shifting supports grid decarbonisation and climate action.

3.1 AIM

This report aims to identify and evaluate strategies that enable university-student renters in the ACT to increase their use of renewable electricity by shifting household demand to periods of high renewable generation. The report evaluates practical and equitable approaches for student renters to actively participate in Australia's clean energy transition.

The most promising solutions are presented as recommendations to key stakeholders, integrating technical, economic, policy, social and environmental insights.

4 METHODOLOGY

4.1 SYSTEMS LIFECYCLE PROCESS

The Human Centred Engineering (HCE) model (Figure 1) was followed to prioritise the direct impacts and benefits for ACT student renters. The process follows an iterative and flexible approach for broad exploration and analyses of the solutions. The model ensures that the solutions do not shift perspectives throughout the model's phases.

The project used the HCE double diamond approach to discover through a literature review, define by creating system requirements, screen solutions against the requirements, and lastly test and validate the solutions to ensure the solutions are of best interest for student renters.

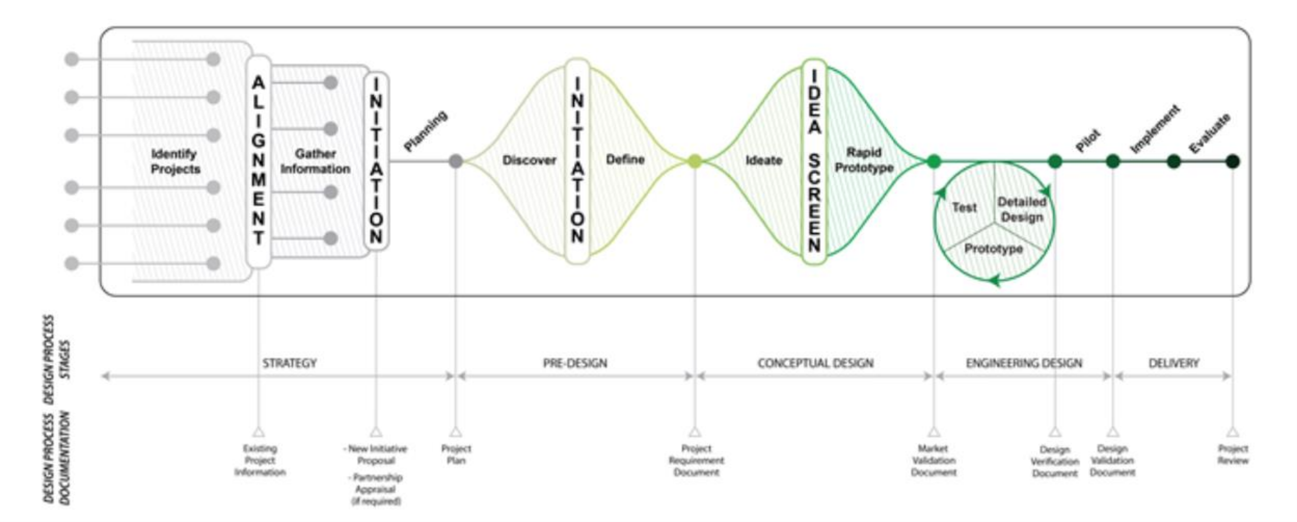

Figure 1: Human Centred Engineering (HCE) Process

4.2 Literature Review

Published media was referenced to identify the issues that are currently affecting rental tenants with respect to the energy transition, the factors influenced by these issues, and the existing policies intended to address them. The referenced media covers publications produced by subject matter experts (SMEs) in the following categories:

- Energy retailers,
- Local, State and Federal Governments,
- Private sector,
- Industry experts,
- Peak/Representative bodies.

The main themes of existing research have been analysed to summarise the state of the renewable energy transition in Australia, energy usage in Australian homes, the prevailing sentiments with respect to renters' attitudes, concerns and hardships surrounding home energy use, and options that are available to renters for adjusting their demand profile to effectively load shift. The literature review supported the creation of solution requirements and provided thirteen load shifting solutions. The research informs the key considerations of the multi-disciplinary validation and analysis for load shifting solutions that improve the social, financial, environmental, and personal wellbeing of renters.

4.3 Multi-Disciplinary Verification & Validation

A set of requirements were created to ensure the solutions meet student renters' unique conditions. Evaluation of how the 13 solutions met the requirements was conducted via a screening matrix. Using the best performing solutions, a shortlist was generated, narrowing down the solutions to four.

The four solutions then underwent a series of multi-disciplinary validations to ensure they were feasible for ACT student renters. Technical analysis looked at the shifting capacity of each solution to determine a kWh/year amount. A policy advisor was consulted to assess the feasibility of developing government policies and programs to encourage uptake of the solutions. Economic analysis was conducted to calculate the net economic value change to rental households as a result of implementing each solution. Net Present Value (NPV) analysis was used to measure the economic value of the solution. Environmental analysis looked at quantifying the environmental impact of each solution using a Life Cycle Assessment. Two SMEs; a socio-technical energy researcher and a government energy program co-ordinator, were interviewed for social analysis. A semi-structured format was followed to allow for flexibility to explore themes of the unique socio-cultural barriers that student renters face. Lastly, a quantitative user survey was conducted on student renters to obtain their perspective and behaviours on energy usage, as well as their capacity and willingness to adopt the solutions.

4.4 Assumptions and Constraints

Table 1 shows the assumptions and constraints that form the basis of the analysis in this report.

Table 1: Assumptions and constraints.

Assumptions	Climate and weather conditions within the ACT will follow a historical precedent.

	Energy data followed the historical and predicted trends from reliable energy modelling sources/data.
	Student renters have limited control over their energy infrastructure.
	Renters are on time-of-use tariff electricity plan, providing a financial benefit to load-shifting.
	Renters live in free-standing off-campus dwellings.
	Student renters have limited disposable income.
Constraints	The target demographic was undergraduate and postgraduate students at universities in the ACT
	Energy modelling of future energy usage, and the subsequent cost-benefit analysis, is based on previous energy usage data and predictions for future energy usage, which may not reflect the actual future energy usage.
	Predictions and the net present value analysis are done within the current and expected future global economic and political climate which is subject to change and can be volatile (e.g. disruptions such as trade wars and pandemics can affect energy prices).
	Solutions must be of a reasonable technological readiness in off-peak periods, meaning that the solution has been tested, effective and verified as fit for purpose.

4.5 STAKEHOLDERS

The report includes recommendations in Section 11.1 that are specific to the below stakeholders.

4.5.1 Undergraduate Student Renters

Student renters have a key interest in the outcome of this report because they are the target demographic for our solutions and the target audience for our survey. The survey results are used to directly validate and inform the final recommendations for how student renters can increase their proportion of renewable energy by adopting feasible strategies for load-shifting.

4.5.2 Government & Private Sector

The government and private sector serve as sources for research into currently available advice, policies and practices relating to the project's aim. For example, the ACT Government developed and provides the framework for the Home Energy Assessment, which incentivises residents to schedule a home energy assessment by offering free merchandise that enables a more energy efficient, comfortable home.

4.5.3 Government Initiative Program Delivery Organisations

Some climate-focused organisations deliver government initiatives focused on improving sustainable practices in renters' homes. They can provide a series of recommendations and methods to either increase their energy efficiency and/or lower the price of their energy bill. The practical delivery of these programs generally takes an hour and are conducted by one person. Any recommendations that result from the findings in this report may be actionable by these delivery organisations and would need to be implemented into their existing operational procedures.

4.5.4 Tertiary Education Institutions

Universities and post-secondary education institutions are considered stakeholders because they can support and facilitate visibility of the findings, student engagement and adoption of any recommendations provided, as well as implementation of any applicable infrastructure or behaviour changes of staff and students within the on-campus residences that align with the project's aim.

4.5.5 Community Organisations

Local community groups and organisations may have an interest in supporting sustainable initiatives based on the project outcome, especially in culturally and linguistically diverse demographics.

5 LITERATURE REVIEW

5.1 THE RENEWABLE ENERGY TRANSITION

Australia's renewable energy transition is an umbrella term given to policies and schemes that aim to reduce the proportion of electricity from fossil-fuel sources (such as coal and natural gas) in the National Electricity Market (NEM)[1], reduce the reliance on fossil fuels in homes and businesses, and replace Australia's dominant source of electricity generation with renewable sources such as solar, wind and hydropower. The goal is to harness Australia's potential for abundant renewable energy to ensure a consistent and reliable energy supply and reduce greenhouse gas

[1] The National Energy Market is Australia's interconnected electricity distribution grid servicing the east coast states and territories of Australia (ACT, NSW, QLD, SA, VIC and TAS).

emissions from the energy sector [9]. The purpose of the renewable energy transition is to meet the 2022 Annual Climate Statement target of net-zero emissions by 2050 under the Paris Climate Agreement.

Electricity demand is expected to rise across Australia over the next 25 years, driven by accelerating electrification. Over the next 20-30 years, least 11 million Australian homes will need to fully electrify [10]. The shift from gas to electricity for water heating, climate control and cooking is projected to contribute 13.7 TWh of demand in 2050 alone, accounting for 12.75% of the total projected electricity demand of 107.5 TWh in 2050, up from 57 TWh in 2024 [11].

5.1.1 Influence of Renewable Energy on Pricing

The Australian Energy Market Operator (AEMO) operates the NEM and sets the wholesale electricity prices based on real-time demand and generation costs, using a merit order system [12]. The cheapest electricity is sold first and is almost always renewable because of the free energy source and low operating costs. When the proportion of renewable energy in the NEM is high enough, the wholesale market price can become negative [13] – effectively paying retailers to consume electricity to maintain balance between supply and demand. Fossil fuelled generators cannot be switched off and the NEM run solely on renewable generators because, although they can respond rapidly to spikes in demand, the long lead time on startup makes it infeasible and expensive to turn off and back on each day [14]. Between 08:00 and 16:00, the spot price is largely dominated by solar energy, from both rooftop and utility-scale sources. However, during peak demand times (between 17:00 – 21:00), more expensive non-renewable sources continue to play a dominant role in the NEM. This reliance is expected to decline as more large-scale energy storage systems are commissioned, and demand can better match renewable electricity supply.

The integration of renewable generators (solar, wind, hydro) and battery storage assets have led to periods where the proportion of renewable electricity available in the NEM is high, especially during the day, leading to a decrease in wholesale prices by $30-$80 per megawatt-hour [13], translating into a reduction in consumer household bills of 8%-22% on average. As renewable generators consistently set lower spot prices in off peak periods, there is a financial incentive to consume as much energy during periods when the proportion of renewable electricity is high.

To achieve complete electrification, at least 11 million Australian homes will need to fully electrify within the next 20-30 years [18]. One of the consequences of the move away from natural-gas powered appliances is that the network supply charge as a proportion of the annual natural gas bill is projected to double by 2050 [10], meaning that customers that remain connected to the gas network will eventually be forced to electrify, even if they can't afford it. This forces consumers to electrify, the barriers of which facing low income households or rental tenants include the high upfront investments and/or the unwillingness of their landlord to cooperate [15] [16].

5.1.2 Effect of the Renewable Energy Transition & Grid Stability

The proportion of renewable energy in Australia's energy market is increasing. From 2023 to 2024, the share of renewable electricity generated rose from 35% to 36%, and coal-fired generation is consistently decreasing [17]. In 2024, electricity from solar accounted for 18% of total electricity generated, with wind and hydroelectric power representing 12% and 5% respectively, and over a fifth of Australia's energy demands are met by distributed energy resources such as rooftop solar systems on homes and businesses [17]. Since 1999, when records of electricity sources of the NEM started, the percentage of renewable sources has grown from 5% to almost 50% (renewable sources are shown in green in Figure 2).

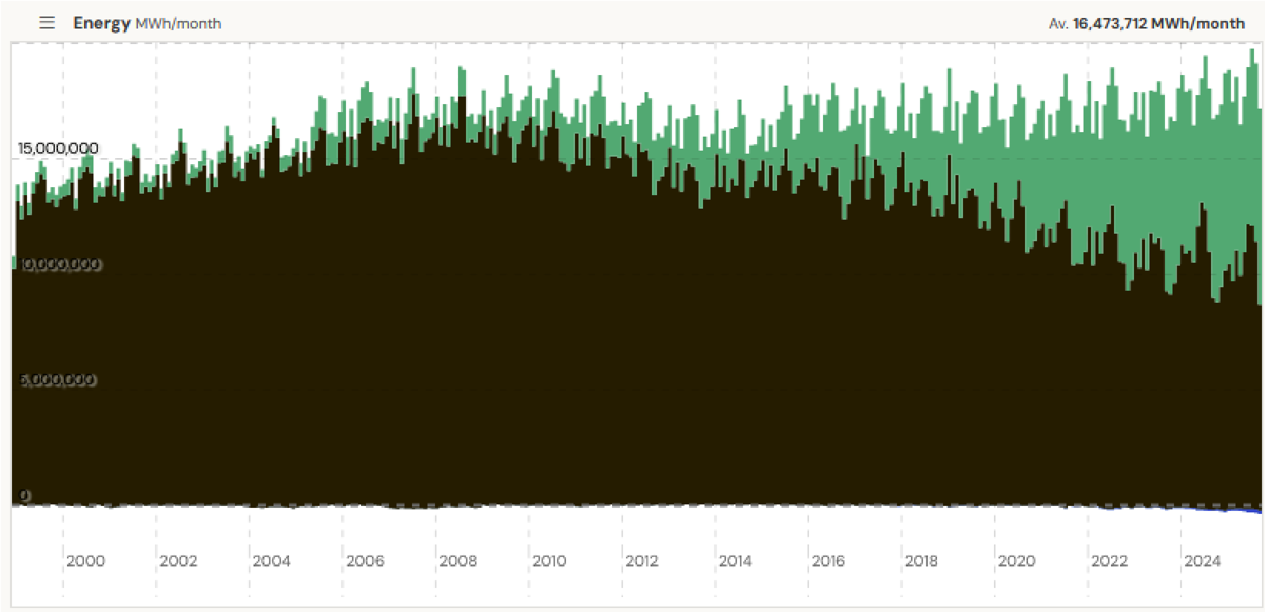

Figure 2: Composition of the energy source (fossil/renewable) over time from January 1999 to September 2025 [8]. Fossil fuel: brown; Renewable: green.

Renewable energy in the NEM is heavily time and weather dependent – for example, solar energy is most abundant during the day and when there is no rain, and wind farms are often most productive at night. This is most evident in Figure 3, showing the composition of the electricity generation sources in the NEM as a function of time.

In Figure 3, the colours correspond to different energy sources.

- Light yellow represents rooftop solar PV on homes and businesses being exported to the electricity grid.
- Dark yellow represents array solar from centralised farms owned and/or operated by utility companies.
- Green represents electricity from wind turbines.
- Light blue represents electricity from hydroelectric dams and pumped hydro schemes such as the Snowy Hydro.
- Dark blue represents the discharging of large-scale battery storage.
- Orange, black and brown represent energy from natural gas, black and brown coal respectively.

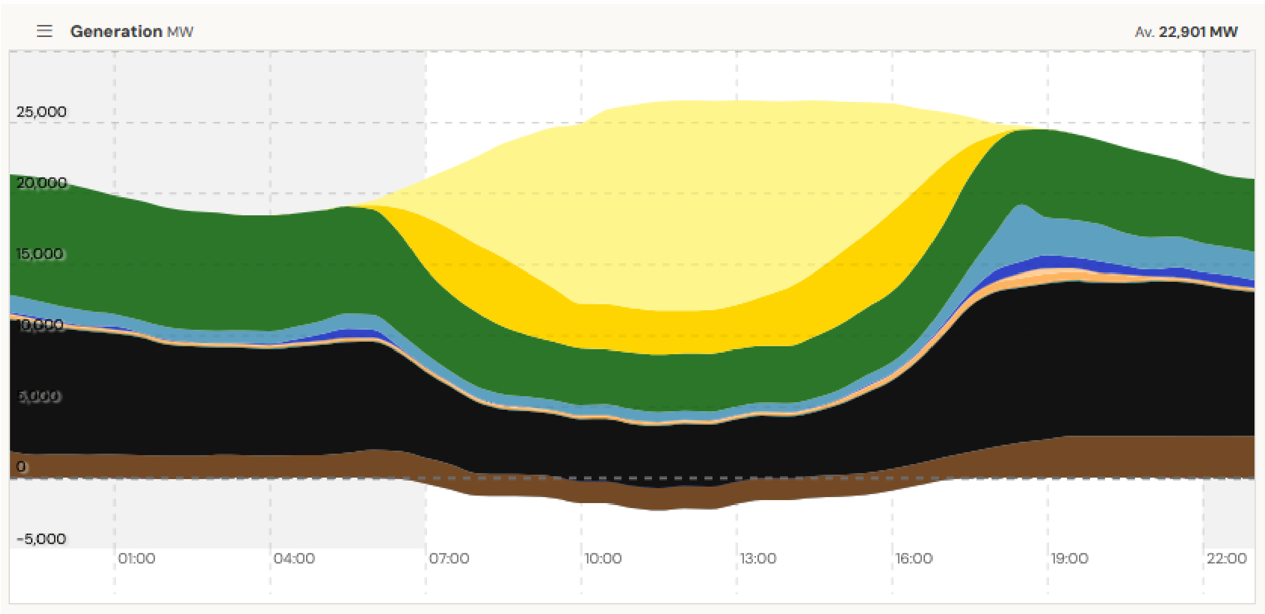

Figure 3: Composition of the electricity generation sources over time on from 00:00 to 23:00 on 11/10/2025. [8]

The NEM must closely match the available electricity generated with the demand from consumers across the country. If supply falls short of demand, the resulting imbalance causes the grid frequency to fall below 50Hz, leading to blackouts [18]. Conversely, when the electricity supplied by the NEM exceeds the demand, the frequency of the grid increases above 50Hz, which also leads to blackouts. To mitigate this risk, during peak demand periods (typically in the morning and evening), fossil fuel generators are often required to meet the increased load. This demand surge is largely driven by everyday schedules and activities such as preparing for or returning from work, using appliances (such as TVs, computers, lights, heating and cooling) and for cooking. Figure 3 shows there is a large proportion of available renewable energy from solar in the middle of the day, so fossil fuelled power stations can spin down temporarily when the generation from solar can meet the demand. This is evident to a lesser extent overnight when electricity from wind energy accounts for a significant proportion of the demand. Overall, it is crucial that the grid is stable and that system maintains a frequency close to 50 Hz to ensure a consistent and reliable electricity supply for all consumers.

Equivalent Carbon Dioxide (CO_2-e) emissions from the power generation sector[2] peaked in July 2007 (Figure 4Figure 4) at 17.7 Mt and have since declined steadily at a monthly average rate of 0.35 $MtCO_2$ per year and can largely be attributed to increasing adoption of renewable technologies and the decommissioning of fossil fuel power plants.

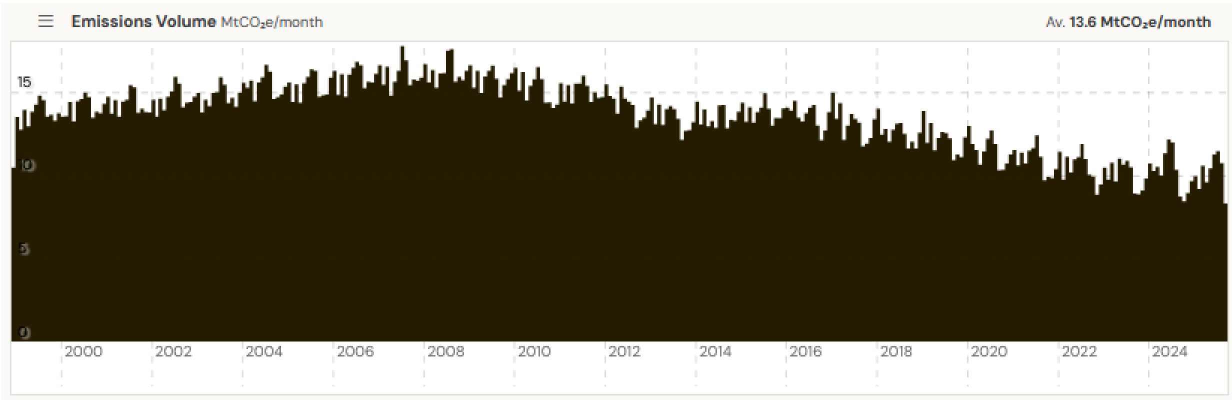

Figure 4: Emissions volume of the NEM from January 1999 to September 2025. Source: https://openelectricity.org.au

As part of the renewable energy transition, the electrification of homes and businesses is projected to add another 50 TWh of demand (with 35 TWh from EV charging alone, supporting 24 million vehicles) by 2050 [11]. Residential, decentralised rooftop solar will almost entirely offset the demand from electric vehicles during the day by supplying 34 TWh [11]. This is contingent on efficiently capturing the produced electricity from rooftop solar by directing it to supply immediate demand or storing it to meet demand at other times. The ACT Government is supporting this approach by investing in 800 MWh of energy storage through the Capital Battery (200MWh) and Territory Battery (600MWh) as part of the Big Canberra Battery Project. These grid-scale batteries will store excess solar and wind energy for use during peak demand, supporting load shifting and grid reliability into the future [19].

5.1.3 The Policy Landscape in the Australian Capital Territory

There are a range of programs currently available to households in the ACT that help them to access energy-reducing and energy-shifting solutions. These include programs from the ACT government, the federal government, and private entities. These include:

- ACT government: Home Energy Efficiency Program helps renters to reduce and shift their electricity usage by providing thick block-out curtains and pelmets for two living areas, as well as draught proofing, an energy saving kit that includes a heated throw rug, cooling towel and thermometer [20].
- ACT government: Social Housing Energy Performance Initiative offers energy efficiency improvements for social housing dwellings [21].
- AGL: Peak Energy Rewards program offers \$5-\$10 bill credits to households that reduce their electricity usage at specific times when requested by AGL [22].
- ACT government: Heating and Cooling upgrade rebate program provides rebates to upgrade from gas heating to reverse-cycle air conditioning [23].
- ACT government: Energy-efficient electric water heater upgrade program provides a rebate for households to upgrade to an electric water heater [24]
- ACT government: Sustainable Household Scheme provides a \$15,000 zero interest loan to improve the energy efficiency of houses including solar panels, household battery storage systems, electric heating and cooling systems, hot water heat pumps (HWHP), and ceiling insulation [25].
- Australian government: Household Energy Upgrades Fund provides low-cost loans to 110,000 existing dwellings to make energy efficiency upgrades [26].

[2] Accounts for the greenhouse gas effects of sulphur dioxides, nitrogen oxides, carbon monoxide and particulate matter normalised to the greenhouse effect potential of carbon dioxide.

- Australian Government: Small-scale Renewable Energy Scheme provides an upfront discount on the purchase price of solar PV or other renewable energy systems if you assign the right to another entity to claim the small-scale technology certificates (STC) from the system [27].

These programs are mostly focused on driving uptake of solutions that require permanent additions or modifications to houses. This means there are many options available to people to own the home they live in, but not for rental tenants.

5.2 CURRENT RESIDENTIAL ENERGY MANAGEMENT METHODS

Households can support the energy transition through various residential energy management techniques. Consumers can engage with funded actions like installing solar panels or upgrading to energy efficient appliances, or free behavioural changes such as adjusting the thermostat settings, or using the clothesline instead of the dryer. These often result in electricity reduction or shifting.

It is crucial that energy consumers are actively involved in the energy transition so residential homes can gain control over their energy use. Building awareness around energy management and its benefits can enhance consumer agency and empowerment. This gives consumers confidence to take action in making informed decisions and adopting energy conservation measures, which is also linked to improved mental and physical wellbeing [28] [29].

An example of a strategy that is supporting this idea for renters in the ACT is the 'Home Energy Assessment.' Run by the ACT Government as a part of the Sustainable Home Advice Program, the assessment involves an energy assessor coming into the rental property and performing a tailored qualitative review of the home [30]. They provide specific advice for the occupant on how to reduce energy consumption and costs and improve home comfort. It also provides the occupants with literature containing several simple ways for how to conserve energy in the form of an Energy Saving Guide.

5.2.1 Energy Reduction

Energy reduction includes any technique that reduces total energy use or improves energy efficiency. It is a popular and widely adopted approach amongst residential energy consumers, with electrification or fuel switching being a common technique for managing energy. Replacing gas appliances with more efficient electricity alternatives, such as heat pumps or induction cooktops, contribute to reducing energy use and allows them to be powered by renewably generated electricity. Installing energy efficient appliances is another common approach to energy reduction.

5.2.2 Load Shifting

Load shifting is a demand side technique where electricity use is shifted in time, typically from peak to off-peak periods.

Load shifting is less popular as a sustainability strategy because it does not lower total energy consumption or carbon emissions on its own like energy reduction techniques achieve. Load shifting can often require lifestyle adjustments and may require smart technologies or appliances which can be barriers for many consumers, particularly low-income renters. Therefore, it is often less adopted and under-utilised.

Despite the challenges, load shifting is valuable for the green transition as it offers significant benefits. By allowing consumers to be more flexible in their electricity consumption, demand can synchronise with times of abundant renewable generation. This can lower peak demand and ease pressure on the grid to support grid stability and reduce the risk of blackouts. For consumers, load shifting can lead to cost savings by taking advantage of lower electricity pricings in off-peak hours.

5.3 RENTAL & LOW-INCOME TENANTS

Rental tenants and low-income consumers are facing exclusion from meaningful participation and contribution to Australia's renewable energy transition. Part of the decarbonisation effort over the last two decades has been the accelerating number of investments by homeowners into 'sustainable investments. Sustainable investments are classed as investments which may work to make homes more energy efficient or provide opportunities for homes to reduce their burden on the grid, for example the instillation of roof top solar panels or home batteries making homes more self-sufficient in terms of energy usage.

Sections 5.3.1 and 5.3.2 outline the particulars of how student renters are being left behind in reaping the benefits of these investments, the reasons behind this and the repercussions.

5.3.1 Barriers to Renter Participation in the Renewable Energy Transition

5.3.1.1 Renter/Landlord Power Dynamic

Renters, and particularly student renters are disproportionately affected by poor quality or energy inefficient housing and have limited ability to action improvements due to the Split Incentive problem [28] [31] [32] [33] [10] [34] [35]

[36]. The Split Incentive problem occurs where landlords bear the initial cost of making improvements to their investment properties, however, do not directly reap the benefit from solutions they may invest in such as energy efficient appliances, roof top solar or improved insulation. The benefits associated with these ‘sustainable investments’ typically present as reduced electricity bills and/or a more comfortable and liveable home both of which reward rental tenants living in the homes. As a result, landlords are less motivated and unincentivised to invest in sustainable improvements to their investment properties because they do not perceive a value in this investment [15] [31] [33] [10] [37].

Additionally, the power dynamic associated with the renter/ landlord relationship in some cases can lead tenants to be reluctant or unwilling to request that their landlord make these ‘sustainable investments’ repairs for fear it may lead to repercussions such as rent increases or requests to vacate [38] [39].

This power balance is additionally exacerbated due to the short-term nature of student rentals tenancies. Median total tenancy periods around Australia average between 12 – 26 months [40] and thus when landlords do choose to make investments in homes, renters have often moved on or been moved on by the time the benefits can be realised.

5.3.1.2 The Cost of Being Low Income

The most recent Universities Australia Student Finances Survey reported the national median full-time undergraduate student income to be $18,300 per year [41], just over 30% of the Australian full- time minimum wage salary of $49,300 [42]. The Australian National University’s official website indicates weekly expenses to live in share accommodation in Canberra (a typical rental share house) at $529 per week, equating to just over $27,000 annually [43]. Student renters are in position of having little to no disposable income to spend on items beyond necessities such as accommodation, food, utilities and clothing and aren’t in positions to make large financial investments to forgo future arising costs.

These financial circumstances have evolved into renters and low-income households suffering from ‘hidden energy vulnerability’, which means that they often struggle to pay bills and forego essential items or services to cover energy costs [44]. These energy costs are typically more severe due to the quality and standards of rental properties often being less than homes with owners as occupants. Additionally, due to the lack of disposable income, renters may be unable to upgrade or replace old or inefficient appliances because of the costs involved, preferring to keep a functional but comparatively inefficient appliance rather than pay upfront for a brand new one.

The lack of capacity to make these upfront investments, which leads to poor quality of life in other aspects, can often result in other material costs for renters that creates a pattern of reduced financial capacity to make upfront investments in the future. Making these sustainable investments to make homes more energy efficient can lead to benefits such as:

- Improvements to their indoor air quality from better climate control, in turn lowering humidity which discourages mould, and lowers concentrations of radon [28]. Air quality is also improved when gas appliances are replaced with more efficient electric models.
- Indoor temperatures are more consistent, resulting in increased thermal comfort. This leads to reduced morbidity and mortality, especially in winter when the outdoor temperatures can fluctuate significantly [28].
- Reduced malnutrition as a direct result of more available funds to spend on higher quality food. This has tertiary benefits in improving mental wellbeing, which reduces family tensions, reduces social isolation and results in higher school attendance and performance [28].

5.3.1.3 Energy Literacy

Energy literacy can be a significant barrier to entry to student renters optimising their own energy use. Student renters, particularly undergraduates are often in their first ‘independent’ living situation post moving out of their family home and have a lack of confidence in their energy knowledge [34].

They find that the available information is:

- **Overwhelming** – Too much information causes decision paralysis, leading to ineffective adoption of strategies. An example of this is information that is visually busy, such as on an energy bill. It has been found that providing too much information can negatively impact comprehension [45].
- **Contradictory** – Information or a recommendation provided by one official source may be contradicted by information from another official source, leading to uncertainty and distrust, especially if there is no single source of truth – for example, official government energy sources such as ACT’s Everyday Climate Choices are also competing with resources from private companies and energy providers attempting to sell energy solutions to consumers [46] .
- **Too technical** – Nearly half (44%) of Australians have a low literacy and numeracy level [45]. This inhibits the comprehension of available sources, which disempowers consumers to remain informed about their energy usage.

- **Inaccessibility** - 20% speak a language other than English at home, so energy information may be in a different language to what they understand; and 20% have a disability that may affect their ability to receive information and make an informed decision about their energy use [39].

5.3.1.4 Effective Engagement

Most households support the energy transition, with 89% interested in reducing their energy use and costs [34]. However, there is low consumer awareness of what the energy transition involves, including its impact on daily life [47] [10] [48] [34]. Many consumers feel as though their efforts to assist in decarbonisation are ineffective, or they lack confidence in current management strategies of the transition [47] [49]. A 2024 Energy Consumers Australia survey found strong consumer willingness to support the transition [48], and key consumer expectations that includes:

- A clear roadmap is required for the transition to renewable energy,
- A Government-led initiative, displaying strong leadership while being fully transparent,
- The distribution of the benefits of the renewable transition and support & incentives should be fair,
- Mis- and disinformation should be addressed quickly,
- Consumers should remain in control of their energy use and be able to know their data is safe, and
- Consumers desire the confidence to make informed decisions.

For renters to be able to participate in and contribute to the energy transition, they need to be effectively engaged and thus policies and programs need to target this demographic through a personalised and nuanced approach. The most effective trusted sources are those from neighbours (i.e. inter-household referrals), community-driven information sessions and independent third parties. Trust in energy providers is low as consumers are often sceptical about the motivations and may assume any advice from their energy has profit driven motives [39] [36] [49].

Mass communication has been found to be ineffective for low-income consumers [29], therefore, the messaging should be simple, action orientated and clearly link cause to effect - actions to tangible benefits [46] [36], for example whether a specific piece of advice will have a financial benefit, health benefit or comfort benefit. Allowing the consumer to choose which measures they adopt to target a specific set of benefits.

The biggest motivators inspiring consumers to change their energy behaviours are general awareness, perceived cost (lower is better), whether there are incentives or rebates on offer, if their comfort will improve, whether it contributes to lower stress, increase health and wellbeing [29], or if there are limited financial implications [36] [45].

However, an additional component of effective engagement surrounding student renters that has been found is their willingness to participate once the information has been shared. Whilst renters may have these motivators and be willing to change behaviours to participate in the energy transition there may be a level of inconvenience associated with those behaviours which cause them to have reluctance. While many households adopt energy-saving behaviours, often their perceived effectiveness is not significant enough to balance the level of inconvenience to the occupants. These individual inconveniences are subjective. The reduction in peak grid demand from behavioural changes in households only leads to a modest annual decrease in energy consumption, which may not necessarily be enough to develop and sustain long-term changes in consumer habits [34] [50].

5.3.2 Market & Regulatory Barriers

The energy market in Australia is comparatively uncompetitive to global markets with few energy providers with distinct plans [51]. This means that consumers tend to stick with a handful of the largest energy providers because there is limited incentive for them to invest time and resources into switching providers. Incentives offered by energy providers in other countries include on-demand tradespeople, free off-peak electricity, discounted or free energy efficiency devices (such as smart thermostats and home automation technology). Some plans offer financial incentives for flexibility with demand, or pre-paid energy plans, which some consumers may prefer to help avoid bill shock [51].

The current options consumers have in Australia for electricity plans are:

- Single rate tariffs: Plans that are not variable based on the time of use but the amount of electricity used. Consumers purchase electricity from their provider at a fixed price of between $0.24-$0.43 per kWh [52].
- Block tariffs: Staggered single-rate tariffs for which the price per kWh increases as consumption thresholds are met. For example, a block tariff may advertise $0.10/kWh for the first 10kWh, then increase to $0.20/kWh for the next 10kWh and so on.
- Time of use tariffs: Tariffs charge consumers a variable rate per kWh depending on the time of day. In peak periods (i.e. in the morning and evening) when overall grid demand is high, the price per kWh will be high. In off peak periods (all other times) the price per kWh will be extremely competitive to incentivise energy use outside of peak periods.
- Demand tariffs: Tariffs which use the maximum rate in kW of electricity drawn from the grid over a set interval. For example, over a half-an-hour interval, a consumer's maximum instantaneous demand could be 5kW, but in the next interval could be only 1kW and would be charged accordingly.

6 System Design

6.1 Requirements

Load shifting is at the core of the report's solutions, as it is an under-explored residential energy management technique.

The requirements for the solution concepts represent the baseline attributes of the ideal concept. The system requirements have been divided into three categories: performance, interface, and stakeholder requirements. These have been developed to produce meaningful solutions for renters, considering their unique financial constraints and lifestyle.

Requirements are weighted on a scale of 0 to 1 where a higher value indicates that the requirement has greater importance when evaluating the solution.

6.1.1 Performance Requirements

<u>R1.0 - The solution must shift demand to peak renewable energy production times</u>

Shifting demand to peak renewable energy production times facilitates the transition towards renewable energy usage. Times of peak renewable energy production occur at both daylight hours due to solar power, and during the night due to wind power. Times of peak energy usage occur in the mornings (07:00 - 09:00) and evenings (17:00 – 21:00). Currently, fossil fuels are required to support electricity demand during peak consumption times. Energy usage during peak renewable energy production times, and outside of peak energy usage times, reduces the reliance on fossil fuels and decreases overall emissions associated with grid electricity.

This requirement has a weighting of 1 because it forms the basis of the project.

<u>R1.1 - The solution should be feasible for year-round application</u>

Year-round application of the proposed solution(s) allows the solution to be more viable for students. If the solution is only applicable during specific times of the year, it is less feasible as a tool to aid the renewable energy transition because it has a lesser overall effect on load shifting capabilities.

Year-round application also addresses differences between higher energy consumption periods and the optimal renewable energy generation seasons. For example, the solution shall be applicable in winter because the highest average seasonal energy consumption is observed in cooler months [53, p. 103]. However, solar production is optimal during spring and autumn weather conditions. As such, variations in household energy consumption and variations in optimal renewable energy production conditions shall be mediated by a solution that is applicable for the entire year.

This requirement has a weighting of 0.8 because the analysis shall favour solutions that allow load shifting behaviours for most of the year.

<u>R1.2 - The solution must increase the proportion of renewable energy used in households</u>

This requirement is related to R1.0.

Increasing the proportion of renewable energy used contributes to the uptake of renewable energy used by households, and conversely, the decrease in electricity from fossil fuels. This requirement assumes that student renters have the ability to be flexible with their energy consumption due to load shifting, and hence have the ability to adapt to the variability of renewable energy generation. It also assumed that the renters' ability to adapt to the variability of renewable energy generation results in higher renewable energy usage in the household. Solutions that meet this requirement will also meet requirement R1.0. This requirement provides robustness to the solutions to ensure that while the household energy demand is shifted to times of peak renewable energy production (via requirement R1.0), these shifts result in increased renewable energy usage in the household.

This requirement has a weighting of 1 because it forms the basis of the project.

6.1.2 Interface Requirements

<u>R2.0 - The solution must be feasible for students renting in the ACT</u>

Feasible solutions for student renters in the ACT are necessary to ensure that they will be used and implemented. Feasibility shall address economic, social, policy, and technical factors that influence the ability for renters to incorporate the solutions into their lifestyles. This requirement exists to address the intersectional qualities of these factors, such that they are considered in tandem to provide solutions that meet the needs of student renters.

This requirement has a weighting of 1 because it forms the basis of the project.

<u>R2.1 - The solution should not interfere with the integrity of the dwelling</u>

This requirement is related to R2.0.

The integrity of the dwelling must not be damaged or irreversibly affected by the solution because renters are not the owners of the home within which they reside. Permission from the homeowner is required before renters can make alterations to a dwelling, which presents opportunities for the alteration work to be denied. This requirement extends R2.0 because the relationship between the homeowner and renter is a social factor that influences the uptake of a solution.

This requirement has a weighting of 0.6 because it underpins a core quality of renters as the target demographic and facilitates the achievement of requirement R2.0.

R2.2 - The solution should be able to be installed and removed by renters

This requirement is related to R2.0.

The installation and removal of the solution by renters improves the accessibility for time- and money-poor student renters. Renters being able to install and remove the solution reduces the necessity for external contractors and the associated costs. This requirement extends R2.0 because the reliance on external contractors is an economic factor that influences the uptake of a solution.

This requirement has a weighting of 0.4 because the ability for a renter to install and remove a solution is heavily dependent on the competency of the individual. As such, the wide range of variation expected in results shall not inhibit the evaluation of a solution.

R2.3 - The solution should be transportable/moveable throughout the lifetime of the product

This requirement is related to R2.0.

Portable solutions allows renters to use solutions as they move between tenancies. Many undergraduate degrees last between three to five years [54], during which time student renters may regularly move. Solutions should be non-permanent and portable so that its lifetime is not limited by the duration of a renter's lease. This requirement extends R2.3 because maintaining the same product between tenancies contributes to the economic viability of a solution.

This requirement has a weighting of 0.3 because the process of transferring leases, which is common for student rentals, means that it is possible for a solution to remain within a dwelling after the resident that purchased it has left. As such, solutions that are immobile shall not be significantly discounted in the analysis.

6.1.3 Stakeholder Requirements

R3.0 - The solution should reduce the cost of electricity for users

Reducing the cost of electricity allows the solution to improve the living conditions of renters. Students typically have below-average disposable incomes, therefore a solution that reduces the cost of electricity will decrease the proportion of their income that is spent on bills [55]. Lower electricity costs may be achieved by reduced net electricity consumption or shifting energy consumption to off-peak times when using a time-of-use tariff.

This requirement has a weighting of 0.6 because reduced electricity costs increase the feasibility of the renewable energy transition, thus empowering student renters to participate.

R3.1 - The solution should be inexpensive to implement

This requirement is related to R2.0.

Inexpensive implementation makes the solution more accessible to student renters. A solution that does not require a large initial investment means that renters are not required to spend a large proportion of their income. Solutions that meet this requirement will also have limited ongoing costs. This requirement means that renters will be more likely to implement the solution. This requirement extends R2.0 because it aims to address the economic factors inhibiting student renters from participating in the renewable energy transition.

This requirement has a weighting of 0.6 because inexpensive solutions significantly impact the uptake of solutions by student renters.

R3.2 - The solution should not increase overall energy costs from baseline

This requirement is related to R3.0.

Overall energy costs should not be increased by the implementation of the solution so that renters are not in a worse financial position than if the solution was not used. If the solution increases overall energy expenses, it will exacerbate the existing inequality of benefits from the renewable energy transition. Overall energy costs, as opposed to strictly electricity costs, are considered in this requirement to accommodate the changes observed on electricity bills from electrification that should be balanced by reduced gas usage. This requirement considers both the electricity costs (as described in R3.0) and changes to gas costs.

This requirement has a weighting of 0.2 because solutions that meet R3.0 may meet this requirement by default, but solutions that do not meet R3.0 may still be recognised via this requirement.

R3.3 – The solution must not increase overall energy usage from baseline

This requirement is related to R3.0.

Overall energy usage must not be increased by the implementation of the solution because the solution shall facilitate load shifting within the existing energy usage patterns of the renter. The process of shifting energy consumption to times of peak renewable energy production does not justify increases in overall energy usage. This requirement works in tandem with R3.0 because solutions that meet R3.0 may also meet R3.3 by default.

This requirement has a weighting of 0.3 because renters may increase energy consumption if energy costs decline, therefore this element of renter behaviour shall not exclude solutions from the analysis.

R3.4 – The solution should not require the landlord's approval to install

This requirement is related to R2.1 and R2.2.

Landlord approval presents the opportunity for the request to be denied, leaving renters unable to implement the solution. Furthermore, to limit the risk of damaging the relationship between the renter and landlord, the renter should be able to make the relevant changes for the solution autonomously. This requirement is related to R2.1 and R2.2 because landlord approval will not be required if it leaves no lasting impact on the dwelling.

This requirement has a weighting of 0.4. This is a desirable requirement because it is ancillary to requirements R2.1 and R2.2.

R3.5 – The solution should be easy to understand and use

A solution that is easy to understand and use increases the chances of it being used by renters. A deep knowledge of the operation and technical basis of solutions is a barrier preventing renters from accessing solutions. As such, solutions that accommodate the greatest proportion of student renters shall be intuitive to use.

This requirement has a weighting of 0.4. This is a desirable requirement because it facilitates the implementation of the solution.

R3.6 – The solution should not inconvenience renters' daily routines

Inconvenience to renters' daily routines is another barrier inhibiting renters from using the solutions and shifting their energy consumption. Solutions that are inconvenient are less likely to be used by renters. This requirement is central to developing a human-centred concept.

This requirement has a weighting of 0.3. This is a desirable requirement because it facilitates the implementation of the solution.

7 SOLUTION SPACE

7.1 SOLUTION CONCEPTS

A set of 13 solutions that can support load shifting were considered and shortlisted into the final four solutions. The process of shortlisting the solutions is described in Section 8. A brief description of the shortlisted solutions is provided below, and descriptions of the other nine solutions are provided in Appendix 3.

7.1.1 Power Point Timers

Power point timers (or simply, timers) are devices that control the flow of electricity to an appliance, allowing renters to schedule when appliances are turned on or off. Timers help to reduce energy consumption by ensuring appliances are only drawing electricity when needed. The two dominant variations are analogue and digital/smart timers. Most analogue timers permit users to set the time on a dial, at which the appliance turns off from up to 24 hours in advance. Smart timers allow the user to remotely control the flow of electricity to the appliance from their phone or other device connected to the internet. Renters should use power point timers to ensure that appliances are used during times of peak renewable energy production and limit the draw of standby power when the appliance is not in use. This is useful when the appliance function is set to run while the renter is out of the house, so that the appliance may be turned off in the renter's absence. It is also useful in situations where large electronics, such as televisions or heaters, shall be turned off while the renter is out of the house.

The estimated cost is $15 based on pricing available at local retailers [56].

7.1.2 Delay Start Appliance

Delay start is a common feature in modern appliances, such as dishwashers and washing machines, that allow users to postpone the function start time for several hours. The delay start feature can be used by renters to schedule appliances to run during times of peak renewable energy production, thus facilitating energy load shifting. Renters should use the delay start feature of smart appliances by pre-loading the appliances and setting the delay to run during times of peak renewable energy production. This is also useful when the appliance function is set to run while the renter is out of the house.

The estimated cost is $500-$2000 [57] [58] [59]. These costs represent the full price of a new appliance, as even the cheaper models on the market contain a delay start functionality. For the purposes of further analysis, the minimum cost in this range of $500 has been used.

7.1.3 Insulation Package

Home insulation functions as a physical barrier that is used to reduce the transfer of heat between the interior and exterior of the house. Insulation uses the barrier to assist in maintaining a consistent temperature inside a home, reducing the need for active heating or cooling and as such lowering the overall energy consumption. Renters should use solutions in the insulation package to contain the effects of heating or cooling devices and extend the period for which the ideal temperature is maintained after the heating or cooling device is turned off.

Thermally Backed Curtains

Thermal curtains (or other heavy curtains) prevent the transfer of heat out of the home through windows and other gaps around the window frame and can also prevent radiant heat from the sun entering the home. Therefore, these curtains are applicable for use year-round.

The estimated cost is $49 [60].

Temporary Double-glazing

Temporary double-glazing prevents the transfer of heat between the interior and exterior of the home through the windowpane. Temporary double-glazing can take the form of any material that forms an additional barrier between the windowpane and the interior of the house. For the purpose of further analysis, it is assumed that this is a thin translucent or transparent sheet of plastic.

This is applicable for use year-round.

The estimated cost is $15 [61].

Door Snakes

Door snakes prevent the flow of air between compartments inside the home, as well as between the home and outside. This reduces the effect of a draught which influences renters' perception of warmth and also creates a contained area for the effect of temperature controlling appliances to be felt, which reduces overall energy consumption.

The estimated cost is $6 [62].

Room Dividers

Room dividers reduce the volume of space within which temperature controlling appliances operate, thereby reducing overall energy consumption.

The estimated cost is $99 [63].

7.1.4 Power Banks

Power banks are a portable, low voltage battery that can be used to charge handheld electronic devices. Power banks can be charged during times of peak renewable energy production for later use, thus functioning as a load-shifting mechanism. Renters should use power banks by charging them during times of peak renewable energy production and using them to top-up small electronic devices during times of peak energy demand.

The estimated cost is $29 [64].

7.2 SCREENING MATRIX

A screening matrix was conducted for all thirteen solutions to determine the shortlisted solutions. Each solution has been evaluated against the requirements on a three-point scale in the screening matrix. The rationales for the achieved scores are shown in the table below. This section details the scores achieved by the shortlisted concepts. The screening matrix for all thirteen concepts can be found in Appendix 4.

Score	*Description*
1	The solution meets the requirement by design.
0	The solution can meet the requirement based on user behaviour.
-1	The solution does not meet the requirement.

Table 2: Performance requirements.

Solution Concept	**Requirement and Weighting**		
	R1.0	**R1.1**	**R1.2**
	Shift demand to peak times	**Feasible year-round**	**Increase proportion of renewable energy**
Insulation Package	**0**	**0**	**0**
Timers	**1**	**1**	**0**
Delay Start Appliances	**1**	**1**	**0**
Power Banks	**1**	**1**	**0**

Table 3 - Interface requirements.

Solution Concept	**Requirement and Weighting**			
	R2.0	**R2.1**	**R2.2**	**R2.3**
	Feasible for students	**No interference with dwelling**	**Installation and removal by renters**	**Transportable**
Insulation Package	**1**	**0**	**0**	**0**
Timers	**1**	**1**	**1**	**1**
Delay Start Appliances	**0**	**0**	**-1**	**0**
Power Banks	**1**	**1**	**1**	**1**

Table 4: Performance requirements.

Solution Concept	**Requirement and Weighting**						
	R3.0	**R3.1**	**R3.2**	**R3.3**	**R3.4**	**R3.5**	**R3.6**
	Reduce costs	**Inexpensive**	**Not increase costs**	**Not increase usage**	**Not require approval**	**Easy to understand**	**Not inconvenient**
Insulation Package	**0**	**0**	**1**	**0**	**0**	**1**	**0**
Timers	**0**	**1**	**1**	**1**	**1**	**1**	**1**
Delay Start Appliances	**0**	**-1**	**1**	**1**	**1**	**0**	**0**
Power Banks	**0**	**0**	**0**	**0**	**1**	**1**	**0**

8 CONCEPT VERIFICATION

8.1 WEIGHTED REQUIREMENTS SCORE

The scores for each solution in the screening matrices shown in Section 7.2 are aggregated and ranked, where the score in the screening matrix is multiplied by the weighting of each requirement. The requirements with a weighting of 1 (R1.0, R1.2, and R2.0) indicate that it is essential that the solutions meet the subject requirements. The shortlisted solutions are comprised of the concepts that had non-negative scores for these three requirements.

Power point timers were determined to be the highest-ranking solution with a total score of 6.3. This indicates that the solution aligns most closely with the desired outcome of the project. Low-ranking solutions i.e. insulation and delay start appliances—have consistent zero scores and positive scores for low-ranking requirements.

Table 5: Ranking of solutions with weighted requirement scoring.

Solution	Total Score	Ranking
Power Point Timers	**6.3**	**1**
Power Banks	**4.9**	**2**
Delay Start Appliances	**1.7**	**3**
Insulation Package	**1.6**	**4**

8.2 SENSITIVITY ANALYSIS

The scores of each solution were recalculated without the consideration of the requirement weightings to assess the impact of weightings on the shortlisted solutions. Power point timers remained as the most favourable solution with a total score of 12. The non-weighted score of the delay start appliances is 3 because the negative and non-negative scores cancel out each other. The non-weighted score of the insulation package is 3 because the solution only has positive scores for three criteria. This comparison of the weighted and non-weighted scores shows that the weightings favour solutions with positive and negative scores over solutions with only positive and zero scores.

The weighting of the requirements did not have a significant effect on the rank outcomes.

Table 6: Ranking of solutions with unweighed requirement scoring.

Solution	Total Score	Ranking
Power Point Timers	**12**	**1**
Power Banks	**8**	**2**
Delay Start Appliances	**3**	**4 ↓ (-1)**
Insulation Package	**3**	**4**

9 CONCEPT VALIDATION

9.1 TECHNICAL ANALYSIS

9.1.1 Purpose

Energy data analysis aims to quantify the amount of electricity that can be shifted by using the shortlisted solutions. The analysis aims to evaluate their effectiveness, identify influencing factors, support economic assessment, and model usage profiles based on appliances, behavioural patterns and temporal variations.

9.1.2 Methodology

The energy data analysis model estimates electricity consumption by combining the watt-hour usage of common household appliances with daily usage patterns and seasonal variations. The model then determines the extent to which each appliance's demand can be shifted given the solution implementation. This is expressed as the number of hours per day that appliance usage can be reallocated to off-peak periods. The potential impact of these shifts is then quantified in kilowatt-hours per year, as an indication of the amount of electricity demand that could realistically be shifted away from peak periods under the given assumptions. These assumptions typically pertained to the number of kilowatt-hours required for typical functions of solutions and their associated appliances/devices.

Research is conducted into the power ratings, frequency of use and model variations of various common household appliances. For research values that provided a range, the average power is taken. Estimating the weekly, daily or seasonal usage in hours, the energy load from each appliance is calculated. Using first-hand experience of being a student renter, assumptions are made on how much energy can be shifted based on how many times it may be feasible to move appliance usage.

A list of appliances, their applicability to each solution, usage frequency assumptions, and wattage are provided in Appendix 5**.**

9.1.3 Outcomes

Under the model's assumptions, power banks can shift all charging demand for relevant appliances (a phone and computer charging once a day), but this is a small percentage of total electricity, at only 0.55%. A conservative approach was taken to estimate benefits of the insulation package, assuming insulation reduces heating and cooling needs by 20% [65] [66]. Yet, if the heating and cooling is turned on in off-peak hours, the insulation will help maintain setpoint temperatures for longer and facilitate less thermal demand needs during peak hours, overall demonstrating significant effectiveness for load shifting, particularly as HVAC is the largest contributor to household energy use [67].

Given the variability in individual household contexts, there is a lack of credible sources that can holistically quantify demand shifting. However, under the relevant assumptions in Appendix 5, the model estimates that delay start appliances can enable 25% of appliance demand to be shifted, and power point timers can allow approximately 10% of appliance demand to be shifted.

Table 7: Summary of Shifting Potential

Shortlisted Solutions:	Total electricity that could be shifted (kWh/yr)*	Shifting potential of total electricity*
Power Point Timers	1,149	10.98%
Power Banks	29	0.55%
Insulation Package	1,545	29.36%
Delay Start Appliances	1,321	25.09%

* Values are indicative, based on assumed appliances and behavioural patterns. Actual results are sensitive to individual user preferences, schedules and consistency of adoption.

Insulation

Insulation is highly effective in reducing heating and cooling demand [65] [66]. It prolongs the retention of set-point temperatures by slowing heat transfer, enabling HVAC systems to be operated during off-peak periods and then turned off during peak demand hours while better maintaining comfortable temperatures in the home.

Coefficient of Performance (COP) is the ratio of heating or cooling energy that is provided per electrical energy consumed and is a metric for HVAC energy efficiency [68]. Reverse-cycle air conditioners provide the highest efficiency for space heating, with a COP typically between 3 and 5, making them significantly more effective than resistive systems [69]. Portable heaters and wall radiators are comparatively less efficient [70]. Heated blankets, while not directly comparable to a space temperature conditioning, are highly effective for personal heating due to direct heat transfer to the user.

Overall, energy savings from insulation are extremely variable and depend on many factors such as HVAC efficiency, room size, existing insulation and technology type. However, fundamental thermodynamic and heat transfer principles confirm that insulation reduces overall energy consumption and strengthens the impact of load shifting heating and cooling devices when used correctly. To be used correctly, the tenant is expected to turn on the AC for approximately an hour before they get home or wake up, given those times of days are in off-peak or shoulder periods. The ability to retain setpoint temperatures is further improved when combined with strong passive design strategies such as the strategic use of a building's orientation, layout and natural features to regulate indoor temperatures.

Power Point Timers

Power point timers can reduce standby power, which refers to electricity drawn by appliances that are switched off but remain plugged in. For example, a desktop computer can use around 8 watt hours when switched off but still connected to the wall [71]. While the individual savings are small, the accumulation across multiple appliances over a year can become significant.

Power point timers may be able to facilitate load shifting for high energy use appliances, such as clothes dryers. This is especially useful for older appliances with manual dial knobs, which can be set to 'on' and then activated automatically when the timer supplies power. Many student share houses still use older appliances, so inexpensive timers can serve as a practical substitute for modern-day delay-start functions. By enabling load shifting without requiring investment into new appliances, these timers increase accessibility and feasibility for students.

Power point timers can also be used to shift heating and cooling demand, which increases effectiveness when paired with good home insulation. A tenant can, program their timer to automatically pre-heat or pre-cool a room before they wake up, arrive home, or go to sleep, ensuring HVAC operations occur during off-peak times. A core challenge in its effectiveness lies in whether the home can retain the setpoint temperature long enough for the tenant to benefit. Timers may also be less effective for students with irregular daily timetables, as programming works best with consistent schedules. However, advanced 'smart' power point timers can be connected to phones via apps, giving the renter more flexible control over their appliances, at the trade-off of higher capital investment.

Power Banks

Power banks are a highly effective load shifting solution because they can store electricity during off-peak periods and then discharge it to power devices during peak hours. Their use, however, is generally limited to low-power appliances such as phones and laptops, as capacity increases with both size and upfront cost.

The energy data analysis demonstrated that a 25,000 mAh Li-ion power bank can shift all electricity demand of a phone and laptop each charged once per day [72] [73]. A further benefit of power banks is that their stored energy can carry over to the next day, ensuring no additional electricity is consumed compared to baseline use.

To maximise effectiveness, power banks should be paired with a power point timer so charging occurs exclusively during off-peak hours, eliminating standby power and optimising load shifting.

Delay Start Appliances

For delay-start appliances to deliver meaningful benefits, households must not only own appliances with this functionality but also consistently use the feature to shift a substantial share of their energy demand.

The analysis shows that appliances best suited to delay-start include dishwashers and washing machines, which can potentially shift their entire energy demand when scheduled in advance. Clothes dryers are particularly impactful due to their high energy consumption, with the model assuming a conventional dryer with a 3-star energy rating uses 2,904 Wh/cycle, yet a 3-star energy rating washing machine uses 901 Wh/cycle [74].

The effectiveness of delay-start HVAC systems, with time controllers on the remotes, is strongly influenced by insulation quality, as heating or cooling during the day when tenants are away requires the home to retain temperatures until occupants return. Aligning HVAC system operation with periods of high renewable energy generation, particularly solar between 8:00-16:00, can further improve load shifting outcome [8].

9.1.4 Recommendations

Maximising energy savings relies heavily on consistent user adoption, which is particularly challenging in student households with variable schedules and low incomes. Solutions are most effective when they require minimal effort or are automated. For example, connecting power boards and mobile devices to timers can reduce standby loads and shift usage to off-peak hours with little active intervention. Increasing battery storage capacity, such as using a portable power station like the AC180 Bluetti (with 1,152 Wh), can increase the amount of electricity shifted as well as increase the pool of appliances that can be powered [75]. Combining power point timers with the insulation package enhances HVAC load shifting, allowing heating and cooling systems to operate efficiently during off-peak periods while maintaining setpoint temperatures. Additional measures, such as heated blankets, can supplement these strategies and be used in combination with timers or power banks for direct personal heating. Overall, solutions that integrate automation, behavioural flexibility, and complementary technologies are most likely to deliver measurable energy savings in student share house settings.

9.2 POLICY ANALYSIS

9.2.1 Purpose

Policy analysis aims to identify and design the most suitable government-led policies for student renters that can be implemented to help encourage student renters to implement the four most suitable load-shifting solutions as identified in Section 7.1. These policies will help overcome barriers for student renters to purchase, transport, and set up these solutions in their homes.

9.2.2 Methodology

This analysis synthesises the qualitative data collected from an interview with a policy expert. This data is used to firstly identify the types of possible policies that may be useful, then to design an appropriate policy for each of the 4 solutions. These insights will help to design a suitable policy that will help student renters to overcome the barriers to implementing these solutions, helping them to shift their energy usage to high renewable penetration times in afou way that considers the convenience and environmental and financial sustainability of each policy, given the specific nuances of these solutions (such as the ease in which they can be self-installed).

9.2.3 Outcomes

The interview with Policy Expert 1 was an informal discussion that was based around two key questions. These were:

1. "What are the general policy options or types available that can be used?", and
2. "What are the considerations that should be kept in mind when designing the details of a policy to ensure it works as intended and avoids unexpected negative implications?"

The interview was approximately 1 hour in length and both questions above were answered in depth. The synthesised answers are provided below in a structured format.

Interview question 1: The discussion about the types of policy options available led to four key types identified: grants, concessional loans, procurement, and regulation.

Policy type	Benefits	Drawbacks
Policy option 1: Grants. A grant involves the government provides a certain amount of money to a target audience, in this case eligible renters in the ACT, to help them buy one of the solutions (e.g. insulation package). The amount would cover the cost of part or all of the solution, and the customer would need to apply or meet some determined eligibility criteria.	• Providing grants has a relatively low administrative cost burden to the government. • Very attractive for renters to access because the grant money does not need repaying and it gives them the opportunity to purchase the type of solution (e.g. correct sized door snakes) for the household.	• Expensive for the government to provide grants. Cost is not recovered like it would be with loans. • Easier for people to gain unfair access to grant money if the eligibility criterion is not strict and enforced. • Likely to distort the market, particularly if the grant value is large and/or the current market for the product in the ACT is small or there is not much competition.
Policy option 2: Concessional loans. A concessional loan involves the government providing a loan to a household at a concessional rate (below market rate) to then purchase the solution (e.g. insulation package). The renter must then repay the loan over a set period. There are usually enforced eligibility criteria, a method for the government to ensure the loan is repaid, and a	• Less expensive for the government than a grant program because the government will get the money back as the loan is repaid.	• Generally higher administrative overheads to government than a grant program. • The government will often engage a third party to administer the loan program, which will incur an administrative cost to the government. Otherwise, the government will still incur and administrative cost of having a government official/s employed

team/department that will administer the loan program.		to manage the loan program and chase up loan repayments. • The renter must pay back the loan over time which is less attractive than getting a grant. The renter is also at risk of going into a debt spiral if they struggle to repay the loan on time.
Policy option 3: Procurement. Procurement will involve the government going out to tender to procure in bulk a certain number of solution/s (e.g. insulation packages) from typically a private supplier, then distribute these to student renters through free delivery programs or communal collection/distribution centres.	• Often easier administratively for renters to access because they do not have to spend time applying for a grant or having to source the insulation package, they just pick it up free of charge from a distribution centre. This will likely lead to greater uptake by renters, particularly if they are distributed at convenient locations such as university campuses or delivered to their house. • The product can be procured by government in bulk, likely for a discount, which is cheaper than each student renter purchasing individually.	• The renter will likely have less freedom to choose the specific type of solution (e.g. the correctly sized thermal curtains) if there is already a predetermined list of options procured by the government, possibly leading to an unhelpful or less optimal product. • The market might be unfairly distorted, such as a particular company wins a big government contract and outcompetes other companies because they can scale up and produce cheaper. This has broader negative economic implications.
Policy option 4: Regulation. Regulation involves a government body tasked with ensuring the market complies with a set of rules and will hold some powers to enforce these rules. These rules are designed based on market consultation and the governments' priorities. They are often used to ensure safety, prevent market issues like monopolies, and ensure smooth operation of markets.	• Ensure products and services meet a standard, which provides certainty for customers. These can be safety standards, operation standards, and many others.	• The market can look unfavourably on new regulation because it often means production and distribution processes need to be change, which can be costly.

The discussion about how to design a policy to be most effective resulted in a list of considerations that should kept in mind when choosing the type and specifics of each policy design. These considerations are useful for preventing common pitfalls and unexpected negative externalities. These considerations follow four themes. These are listed and described below:

Theme 1: Balance the efficiency of bulk-buying with the efficiency of tailored solutions.

- Consider how much the student renter needs to tailor the solution to their needs. A door snake may not need much consideration because most doors are of similar size, but curtains and pelmets need to be tailored to window size. Therefore, the customer may prefer to have a range of options available to them for some items more than others.

Theme 2: Prevent unintended market distortions.

- Ensure the policy encourages uptake at the desired rate by using an incentive at the right strength (for example, higher monetary offerings can lead to faster uptake) which can lead to a shortage. However, a shortage can be mitigated if the market responds by increasing supply.
- Increasing the demand for solutions by decreasing the barrier to entry (through a grant, concessional loan or procurement) can cause the price in the market to increase. This can be hard to avoid but is important to be aware of in the broader market context.
- Consider the secondary market impacts. For example, providing thermal curtains and pelmets for free could see a decrease in demand for blinds and other window coverings.

Theme 3: Accessibility

- Consider how accessible these solutions are. For example, rural households may not be able to buy thermal curtains, so they are unintentionally excluded from accessing the benefits of this policy.

Theme 4: Consider other externalities, such as health and wellbeing.

- Consider the health impacts of the solutions. For example, thermal curtains would also provide darker rooms which may help people to sleep if they previously had large amounts of streetlight coming through their bedroom windows.

9.2.4 Policy Recommendations

Given the 4 types of policies that can be designed, and the 4 themes of considerations that should be taken into account when designed the policies, the following suite of policy options for each solution are optimised to maximise benefits while reducing the consequence and likelihood of risks.

Power point timers and power banks

The optimal policy type for the power point timer solution and the power bank solution is **procurement with centralised distribution and light regulation of access.** The government would purchase power point timers and power banks, ideally in bulk, from a domestic manufacturer/supplier that aligns with the appropriate government procurement guidelines. The timers and power banks would be distributed to university students for free at university campuses including ANU and the University of Canberra (UC). Minimal advertising would be necessary, and a good starting point would be a mention in the weekly university newsletter. Power banks could be used for unintended uses such as phone charging at night, so a pamphlet should also be distributed in tandem, outlining how best they can be used for demand shifting activities.

This method of handing out timers and power banks at an accessible location to student renters is very convenient for getting lots of timers and power banks into the hands of students and does not require them to do burdensome administrative work such as making a formal application for a grant to then purchase the timer from a retail store. Students can pick up as many as they need for their household, so one person could feasible bring back one for each of a four-person household, saving the others from also having to visit the dispatch location.

There is a risk that students who don’t rent their residence would also be able to claim a free timer or power bank, but the effort to check their rental status is not worth the benefit of power point timers or power banks being provided exclusively to student renters. Another risk is that students could claim more timers and power banks than they need to on-sell or gain value otherwise, however this is mitigated by the resale value being low.

Insulation package

The optimal policy type for the insulation package solution is **procurement with personalised distribution and carefully regulated access.** The government would purchase the insulation package components ideally in bulk from a domestic manufacturer/supplier that aligns with the appropriate government procurement guidelines, with variety of size where necessary, e.g. curtain and pelmet length. Student renters can sign up for free through an online portal (delivered by ACT government) and select the sizes and number of items they require, and a time for a delivery unit to visit your house and deliver the insulation package (thermal curtains, door snakes and room dividers) for free. The renter can then install these by themselves. Use proof of student ID to confirm the recipient is a student, and proof of residence to ensure they rent their residence.

This solution is difficult to transport home especially if no one in the household has a large car. Therefore, providing a free delivery service will encourage uptake. Renters have the skills to install these solutions because the installation is intuitive, and the cost of paying for an installer’s time could be expensive. This aligns with Requirement R2.2, but would require the renter to have access to the internet to use the portal to claim the free insulation package. This is unlikely to be a significant barrier due to the ubiquitousness of mobile phone ownership and access to the internet facilities offered by their university.

Delay timers

The optimal policy type for the delay timer solution is **regulation to standardise all washing machines, dryers, and dishwashers to include in-built delay timers.** A monetary policy, such as a grant or loan, would not be appropriate here because to encourage an uptake of delay timers would require an uptake of expensive appliances such as washing machines, and the payoff is unlikely to be worthwhile. However, regulation is a no (low-cost, when considering the administrative cost to government to implement the regulation) cost option that would ensure all new washing machines, dryers and dishwashers have delay timers in-built. The impact would take time to eventuate, but eventually, all student renters would have delay timers in-built into their appliances. Uptake could be slow due to the comparatively long life of large appliances (such as washing machines, dryers and dishwashers) that are replaced infrequently.

9.3 ECONOMIC ANALYSIS

9.3.1 Purpose

The economic analysis in this report aims to quantify the net economic value change to rental households as a result of implementing each solution. Associating an economic value or monetary value to potential solutions is meaningful within the capitalist market of Australia and particularly important in this case due to our financially constrained user base, as described in Section 5.3.1.2. Economic analysis will determine the financial feasibility of possible solutions for renters as well as potential financial benefits of solutions in order to determine the likelihood of solution uptake. This analysis allows for recommendations to be made based upon the economic performance of solutions.

9.3.2 Methodology

Economic analysis will be undertaken through a Net Present Value (NPV) analysis. This method measures the value of the asset while considering:

- The initial capital outlay of purchasing the solution
- Economic gains made from energy bill savings as a result of shifting energy consumption
- Lifetimes of solutions
- The time value of money

NPV analysis is particularly useful in finding the true economic value of solutions as money received today is not worth the same as money received in the future [76], thus a simple comparison of money spent and savings made is not a true evaluation. The NPV equation used combines a traditional NPV formula with an annuity formula that incorporates the consistent annual cashflow potential from energy savings (Equation 1) .

Equation 1: Net Present Value.

$$\frac{X_n * (1-(1+i)^{-n})}{i} - X_0$$

$$X_0 = Initial\ Investment$$

$$X_n = Cash\ flow\ in\ time\ period\ n$$

$$i = Discount\ Rate$$

$$n = time\ period$$

Analysis Assumptions:

- Savings from energy bills are considered cash flows as they are financial gains from energy bills in the 'baseline scenario' where no solution is implemented.
- Renters are on electricity plans which include 'time of use tariffs', see Section 9.3.2.1.
- Total energy shifted follows assumptions made in energy analysis and outcomes and are assumed to be constant annually over the lifetime of the solution.
- Given the investment is being made on an individual basis and assuming low risk tolerance, a discount rate has been chosen based on an assumed interest rate on a 'typical' savings account. A typical rate has been assumed as 4% [77]. The discount rate also takes into account inflation; the mean inflation rate of the last 2 years has been taken at 3.325% [78]. The combination of these rates, using the formula in Equation 2 leads to a discount rate of 0.00653.

Equation 2: Discount rate.

$$r = \frac{1+r'}{1+i} - 1$$

$$r' = nominal\ interest\ rate$$

$$i = inflation\ rate$$

Given the varying lifespans of solutions, an additional equation was used to standardise the NPV results. This allows for direct comparison between solutions (Equation 3).

Equation 3: Standardised NPV.

$$\frac{r * NPV}{1-(1+r)^{-n}}$$

9.3.2.1 Time of Use Tariffs (TOU)

It is assumed that all renters using the proposed solutions are on TOU electricity tariff plans and thus will reap economic benefits from shifting their energy usage to 'off peak' periods. This assumption has been made based on the need for variable tariffs to reap financial rewards from varying energy usage, coupled with recent legislation making this assumption valid into the future. At the end of 2024 the AEMC regulated the use of and upgrade to Smart Energy Meters across the NEM by 2030. This policy is beginning to be actioned in late 2025 and will mean that by 2030 all households in the NEM will be able to be on TOU plans. Smart Meters have the ability to read energy usage at periodic time intervals allowing electricity providers to distinguish between energy usage at peak and off-peak times [79].

ActewAGL hold the highest market share in the ACT at 74% (as of Q2 2023-2024) and have been used as a data source to validate other areas of analysis. In the ACT, the residential standard plan customers are charged based on times as below on a c/kWh basis as of July 2024 [80]:

Table 8: ActewAGL Electricity prices as of July 2024.

Category	Time	Cost ($)	Cost Difference from Peak Time ($/ kWh)
Energy Usage at Peak Time	7:00 – 9:00, 17:00 – 21:00	0.4334	0
Energy Usage at Shoulder Time	9:00 – 17:00, 21:00 – 22:00	0.2988	0.1346
Energy Usage at Off-Peak Time	Usage at all other times	0.2640	0.1694

9.3.3 Outcomes

When analysing results, success criteria is firstly assessed on whether the NPV is positive or negative. A positive result indicates a worthwhile economic investment, and a negative result indicates a not worthwhile economic investment. Additionally, the magnitude of the result determines how 'worthwhile' the investment is in terms of payback for the renter, which accounts for initial investment and savings from reduced energy bills.

Table 9: Standardised NPV results.

<table>
<tr><th>Solution</th><th colspan="4">Standardised NPV Results for Shifting Energy Usage to Off Peak Times</th></tr>
<tr><th></th><th colspan="2">100% Off peak ($)</th><th>100% Shoulder ($)</th><th>50% Off Peak, 50% Shoulder ($)</th></tr>
<tr><td>Power Point Timers</td><td>111.02</td><td>87.55</td><td colspan="2">99.28</td></tr>
<tr><td>Delay Start Appliance</td><td>194.71</td><td>141.09</td><td colspan="2">167.90</td></tr>
<tr><td>Insulation Package</td><td>247.96</td><td>185.22</td><td colspan="2">216.59</td></tr>
<tr><td>Power Banks</td><td>-21.30</td><td>-22.48</td><td colspan="2">-21.89</td></tr>
</table>

Economic analysis was also conducted on the minimum shifting required to make an investment in solutions economically viable i.e. producing a positive NPV. The methodology behind this analysis can be explained through: If the renter shifts their energy usage in X% of the potential times they could shift (based on energy analysis), the solution will become economically viable.

Table 10: Shifting required for economic viability.

Solution	Minimum Shifting Required over lifespan for Economic Viability	
	Into Shoulder Period (%)	**Into Off Peak Period (%)**
Power Point Timers	2.68	3.38
Delay Start Appliance	25.30	31.86
Insulation Package	18.71	23.56
Power Banks	472.79	595.23

9.3.4 Recommendations

The economic analysis has been conducted in two ways, both using Net Present Value as a baseline methodology. First through understanding the economic NPV of solutions over the course of their lifetime and secondly through analysing how much a solution must be utilised before it becomes economically viable. Due to the nature of student renters, the latter is deemed as a particularly important analysis tool, as discussed in Section 5 of the report. Students have unique lifestyles and values which influence their uptake and willingness to make economic investments, therefore solutions with the lowest economic barrier to entry will have a higher likelihood of uptake.

Based on analysis method 1 (the NPV of the solution), insulation packages are deemed to provide the largest economic payback to renters over their lifetime and therefore are the most highly recommended. This is followed by delay start appliances and then power point timers. Power banks produced a negative result and thus are not recommended as an economic investment for renters as over the course of their lifetime the initial capital investment is never returned through energy savings.

Based on analysis method 2 (the required uptake of the solution) power point timers require the least uptake by a large margin to be economically viable and thus are most highly recommended. This is followed by delay start appliances and then insulation packages.

Power banks produce a value of over 100 (761 and 604 respectively). A value of over 100 indicates that no matter the usage percentage they can never be economically viable, they would need to be used 761% of the available times, an impossible recommendation. These results again confirm that Power Banks are not recommended as an economic investment.

9.4 Environmental Analysis

The environmental analysis of the shortlisted four solutions utilised a Life-Cycle Assessment (LCA) completed based on the provisions of ISO 14040-2006 Environmental Management – Life Cycle Assessment – Principles and Framework.

9.4.1 Purpose

The purpose of this LCA is to conduct a quantitative analysis of the dominant components of the shortlisted solutions. The results of the LCA will inform the environmental impacts of raw material extraction for each product. The functional unit is a load shifting solution system applied to the entire house.

The cut-off values for the assessment were materials that constituted less than 1% of the total mass. The electronic components of solutions were excluded from analysis due to the large number of materials that constitute less than 1% of the total mass.

The calculation considers the solution suites are applied across a four-bedroom house. The application of the solution suites to a four-bedroom house includes the following assumptions:

- Three power point timers are used in total, being applied to a wall radiator heater, washing machine and dryer.
- Five door snakes are used in total, with one applied to each bedroom door and one being applied to the front door of the dwelling.
- Five sets of temporary double glazing are used in total, with one applied to each bedroom and one being applied to the living area of the dwelling.
- One room divider is used in the living area of the dwelling.
- Five thermally backed curtains are used in total, with one applied to each bedroom and being applied to the living area of the dwelling.
- Four power banks are used in total, with one being provided to each resident.

9.4.2 Life-Cycle Inventory

The following table displays the material inventory of the products considered in the assessment. Electronic components of the products are excluded from analysis due to the complexity of quantifying the masses of each material. As such the power point timer, dishwasher, washing machine, dryer and power bank electrical components have not been represented in this assessment.

Table 11:Inventory of product materials included in analysis.

Material									
	Power Point Timer		Power Bank	Delay Start Appliance			Insulation Package		
			Dishwasher	Washing Machine	Dryer	Thermally Backed Curtains	Temporary Double Glazing	Door Snake	Room Divider
Polypropylene			4.307						
PET			1.017	11.499	9.512		0.424		
Polycarbonate	0.045	0.077							
Polyurethane								1.524	
Polystyrene			0.011						
Polyester								0.256	0.068
LDPE Film			2.169						
LDPE Resin			0.662						
Nylon			0.698						
Synthetic Rubber			0.477						
Stainless Steel			23.490	31.785	16.495				5.669
Cotton						2.175			
Glass				1.820	1.232				
Concrete				19.676					

9.4.3 Impact Assessment

The impact assessment method used is the CML-IA baseline method, which categorises material into 11 environmental impact indicators. The indicators are a method of identifying specific environmental concerns caused by the processes used in the procurement and production of materials. Of these indicators, the impact categories of greatest interest for this report at the fossil fuel depletion (MJ) and global warming (kg CO2 eq). Fossil fuel depletion, denoted as 'Abiotic Depletion (fossil fuels) (ADP)' in the CML-IA baseline method, represents the amount of fossil fuels depleted in a process as an amount of energy (MJ). Global Warming (GWP) represents the effect on global warming caused by a process in terms of the amount of CO2 that would cause the equivalent effect.

The impacts in these two categories were calculated, and the relative result for each product is shown in Figure 5. The relative results show the impact of each product represented as the proportion of the highest value.

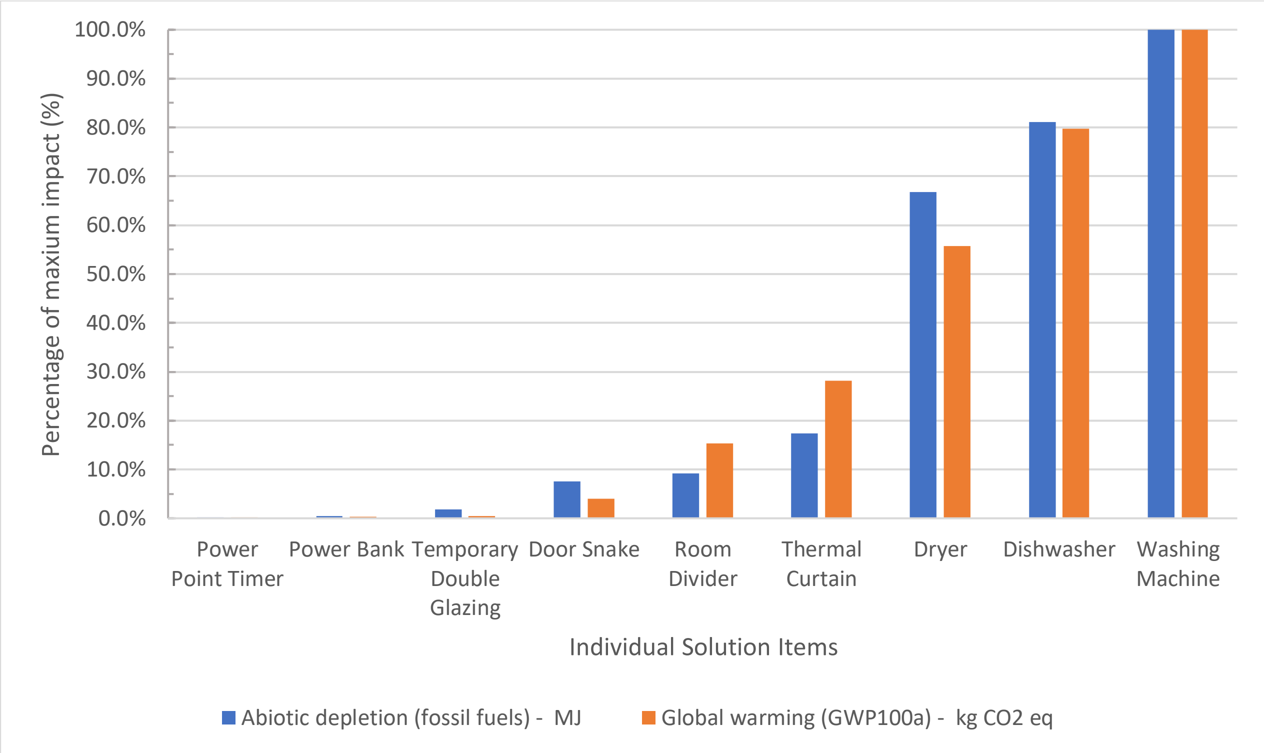

Figure 5: Relative environmental impacts for individual products as compared to the product with the greatest impact.

All the appliances have greater impacts in both categories as individual products, which may be attributed to the amount of material used in the production of these products. Washing machines have the highest impact in both abiotic depletion and global warming due to the high amount of steel constituting the product as compared to the other delay start appliances. Washing machines deplete the equivalent of 1527 MJ of fossil fuels and emit 180 kg CO2 equivalent. Stainless steel comprises around 49% of the appliance's total mass and contributes to 49% of the abiotic depletion (753 MJ) and 84% of the global warming impact (151 kg CO2 eq). Polypropylene (PP) is also a significant contributor to the total impacts in washing machines. PP comprises 18% of the appliance's total mass and contributes to 49% of the abiotic depletion (747 MJ) and 14% of the global warming impact (24 kg CO2 eq). The impact contribution of PP compared to its proportion in the total mass indicates that the material has significant impacts with respect to fossil fuel depletion. This is further demonstrated by the impact results of the dryer. PP comprises 34% of the dryer's total mass and 61% of its fossil fuel depletion impact (618 MJ).

The timer and power bank both have low relative impacts due to their size and the method of measuring their component materials. These products have a total mass under one kilogram, resulting in significantly less material being processed in production. The double temporary double glazing similarly has low impacts due to its small quantity of materials.

Door snakes have higher impacts than the timer, power bank and double glazing. The greatest contribution to impacts for the door snake is polyurethane, which is due to the higher proportion of polyurethane compared to polyethylene terephthalate (PET). PET in door snakes constitutes 2% of the total mass and less than 1% of the fossil fuel (2 MJ) and global warming (0.05 kg CO2 eq) impacts. This indicates a slight difference in the impacts per unit mass caused by each polymer, such that polyurethane material has greater abiotic depletion and global warming impacts than PET material.

Interestingly, the thermally backed curtains have a greater impact on both abiotic depletion and global warming than room dividers, which are both products that integrate the use of textiles. The thermally backed curtains are primarily composed of cotton, while the room dividers are a combination of stainless steel and polyester textile (PET). Room dividers contain a greater amount of stainless steel than the mass of cotton in the thermal curtains, however the cotton in curtains results in higher impacts in both categories. This elucidates that cotton is a high-impact material.

The products that are not appliances mostly have a higher proportional impact on fossil fuel depletion that global warming, indicating a similarity in the use of fossil fuels between non-appliance products than GHG emissions. This implies that the fossil fuel energy required for material production is less than the GHG emission caused by material transformation processes. While this assessment of relative environmental impact is normalised to the total impacts of the washing machine, it provides a frame of reference to compare the two impact categories.

The relative results of the two impact categories for each solution suite are shown below in Figure 6. It demonstrates the compounding effect of applying the products across a four-bedroom dwelling. The delay timer solution suite—which includes a washing machine, dryer and dishwasher—has the greatest total impact of the four suites. The insulation suite—which includes one room divider, five thermal curtains, five door snakes and double glazing applied to five windows—has the second greatest impacts. While the timer and power bank solution suites both assumed four products are used in the household, their minimal unit impacts means that the suite also has minimal relative impacts.

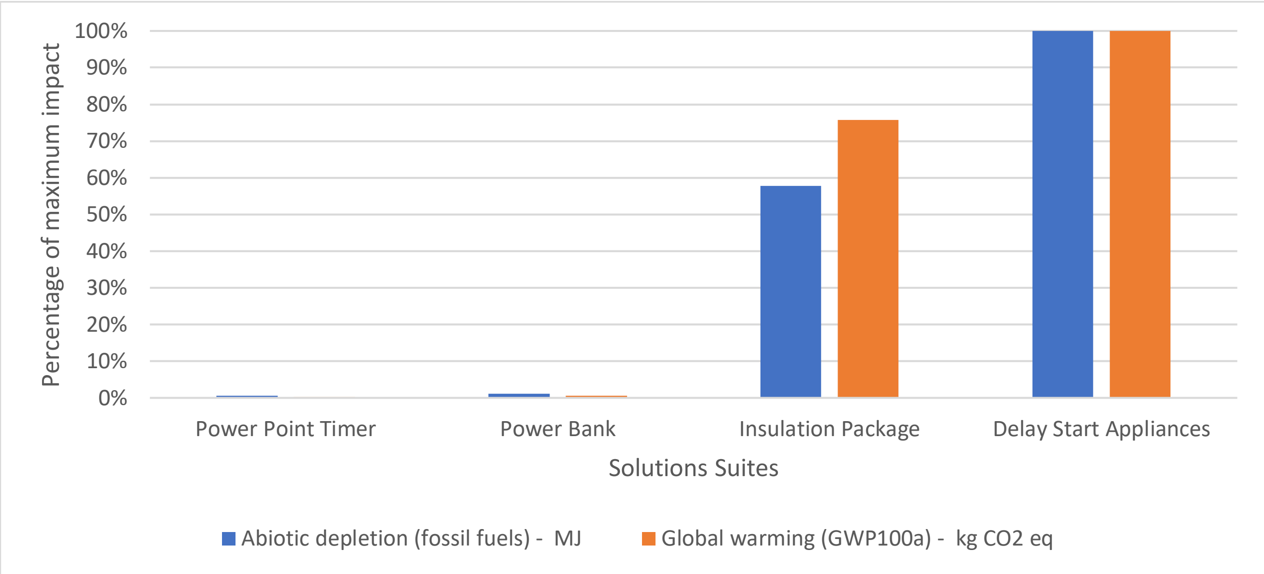

Figure 6: Relative environmental impacts for each solution suite as compared to the suite with the greatest impact.

9.4.4 Interpretation

<u>Results from Life-Cycle Impact Analysis</u>

Timers and power banks prove to have lesser impacts in the fossil fuel depletion and global warming impact categories. Delay start appliances have the greatest impacts of all products assessed. Of the products comprising the insulation suite, the product with the greatest impact—being the thermal curtains—induces less than 30% of the fossil fuel depletion and global warming of the maximum impacts observed by the washing machine. As such, the individual products within the insulation suite are favourable for their limited relative impact. While the insulation suite has impacts between 50-80% of the maximum observed by the delay timer suite, the insulation suite is composed of 16 products while the delay timer suite is composed of three. The products within the insulation suite allow for more comprehensive changes to the household, as they are applied to bedrooms and main areas.

It was observed that the cotton textile in the thermal curtain had greater impacts than the polyester textile in the room dividers. Polyester has a fossil fuel depletion potential of 78 MJ and global warming potential of 6 kg CO_2 eq, while cotton textile has a fossil fuel depletion potential of 122 MJ and global warming potential of 23 kg CO_2 eq. While this suggests that polyester materials should be favoured for products in the insulation suite, the regenerative nature of organic fabrics and their ability to biodegrade shall be considered. Furthermore, the thermal properties of cotton may prove to be more effective at home insulation than synthetic fabrics.

<u>Fossil Fuel Depletion Payback Period</u>

The payback period for the fossil fuel used in the production of each solution is determined by the number of years of shifted energy required to offset the fossil fuel depletion. The amount of shifted energy per year is determined as provided in Section 9.1 (Technical Analysis). Table 12 shows the amount of time for the production fossil fuel depletion to be offset by the solution's use of renewable energy via load shifting.

Table 12: Load Shifting Payback Period of Fossil Fuel Use

Solution	Fossil Fuel Depletion (MJ)	Payback Period
Power Point Timer	11.5	1 day
Power Bank	25.9	4 months, 4 days
Insulation Package	2184.4	3 months, 22 days
Delay Start Appliances	3786.3	2 years, 1 month, 29 days

The power point timer has the shorted payback period, indicating that the fossil fuel consumption required in the production of the solution is offset by the load shifting capability of the solution after one day. The insulation package also shows favourable outcomes for the payback period, where in under four months the fossil fuel depletion of production is offset by its load shifting capability.

9.5 SOCIAL ANALYSIS – INTERVIEW WITH SUBJECT-MATTER EXPERTS

9.5.1 Purpose

Social analysis aims to gain perspective on socio-cultural barriers that student renters may face. This is particularly important as student renters typically have low incomes and are faced with a power dynamic with their landlord. Understanding this perspective will verify that our solutions are of interest and aligns with student renters.

9.5.2 Methodology

Two Subject Matter Expert (SME) interviews were conducted in a semi-structured format. A set of open-ended questions were asked to facilitate flexibility to explore and follow up on any ideas. The set of questions are outlined in Appendix 7. Pseudonyms were used as the de-identification method

The transcript and recordings were analysed using a manual thematic analysis as outlined in Social Research Methods by Adam Bryman, to discover the common themes and language used [81].

9.5.3 Results

The two SMEs are Mark and Mary. Mary is a research fellow at an Australian University, who investigates socio-technical responses to energy transitions. Mark works for government funded programs that work with ACT rental households to assist them in improving their energy efficiency.

Theme 1: People's motivations to engage in household energy practises differ depending on their primary concern, which is ultimately influenced by their capacity.

When asked the question: "*Do people have differing motivations to engage in household energy practises?*" Mary and Mark identified different words, care and priorities. However, it became clear that they were describing the same idea; that people's motivations differ depending on their primary concerns. The follow up question "*Are there different barriers that different demographics face, particularly student renters?*" further solidified this, as both SMEs discussed student renters being time stretched due to challenging priorities.

In the interview with Mary, she discussed that when interviewing participants for her own research, she prioritises asking "why" to discover what they truly care about and what their burning value is.

"*People invest and value things they care about...cost efficiency is common as it has to drive what we do because it is our primary unit of trade or capacity...so it is always in the conversation*".

Similarly, Mark discussed how there is a difference in the type of engagement between low-income earners and higher-income earners. They have differing priorities, with low-income earners typically participating in the programs for the free incentives and to lower energy costs.

"*They [low-income earners] are not able to think ahead as they are financially stressed and concerned. The more affluent they are, the more they start also caring about the environment and community, in addition to saving money.*"

Both Mary and Mark identified financial stress as a low-income earners primary concern. This was first identified in the section 5.3.1.2, and was then reflected in the design requirements.

Similarly, when the follow up question was asked, Mary and Mark discussed challenging priorities that lead students to be time-poor and stretched. They identified the challenges that students face juggling the cost of living, pursuing higher education, and working. Mark explained:

"*My understanding is that due to their busy priorities and challenges, [energy] is the last thing on your mind, unless you can stabilise all the other stresses that come through, there are a lot of other things to consider first. Student renters are aware of the secondary impact, you're doing good to the community, you're doing good to saving the environment.*"

Mark believes this is one of the reasons why young adults are the lowest cohort to participate in the energy programs. Mark recounted a story about when he visited a student share house in Braddon, Canberra, that had signed up for the energy efficiency program. They told him that they were aware of the program for a long time before finally signing up to it. Mark asked why, and they told him that it slipped their mind and that they forgot as studying and work were prioritised.

Mark and Mary's answers to both questions verge on the same reasoning. Motivation and barriers are driven by concern and capacity. These findings align with the project's understanding and hence with three of the stakeholder requirements:

R3.1 The solution should be inexpensive to implement

R3.5 The solution must be easy to understand and use

R3.6 The solution should not inconvenience renter's daily routines

These requirements were created to try and address the issue of the limited capacity that student renters face. Both SMEs agreed with the requirements.

Theme 2: Simple solutions and the Landlord power dynamic

During the interviews, both SMEs verified the project's requirements and top four solutions. Mary agreed with the stakeholder requirements and stated that they constrained quite a lot. She liked the solutions and identified them as '*simple but effective'*. Similarly, in Mark's interview he agreed with the system requirements and solutions. He also discussed the simplicity of the solutions. He mentioned that they do not focus on heating/ cooling, which are the main sources of household energy usage. In both interviews, the team discussed how the requirements constrained as they were created to consider the Landlord-Renter power dynamic, and how the project focuses on solutions that are student renter friendly and do not require approval from the landlord.

Mark was asked the question "*Do you find that renters engage with their landlords to help fix problems in their house?"* Mark discussed that it is still a challenge despite legislative changes in the last few years, as discussed in section 5.1.3. Mary also strongly agreed that there is still a power dynamic. She identified that the project is a pragmatic approach, she used the analogy of hospital triaging, and how the project focuses on primary care, rather than looking to address systemic changes. Mary emphasised that future work needs to consider updates to infrastructure, policies, and societal shifts:

"*It's not actually just the community's responsibility or an individual's responsibility...It is totally reasonable to empower students to do their own stuff, but it's not reasonable to expect them to solve this ridiculous level of complexity by themselves*."

The issue of the landlord power dynamic was first identified in section 5.3.1.1. Two requirements were created to produce a solution space that would avoid placing renters in compromising situations with their landlord. For example, engaging in the landlord approval process, and applying to get their bond back after moving out. Both SMEs agreed with the requirements to address this.

R2.1 The solution must not interfere with the integrity of the dwelling

R3.4 The solution should not require the landlord's approval to install

Theme 3: Communication, engagement and capacity

Throughout the interviews, both SMEs regularly discussed the importance of communication. Mary first recounted a story about when certain areas in South Australia moved to time of use tariffs and energy retailers passed this cost down to customers without informing or educating them. This negatively affected communities as they were left paying high energy bills without understanding how they could have prevented this. She emphasised that access to communication and knowledge sharing is crucial to empower and support student renters in the energy transition. Similarly, Mark discussed how the programs aim to create flyers and information accessible and easy to understand.

"There is a lack of education in schools surrounding life lessons such as money management and budgeting, let alone energy literacy and efficiency methods."

Mark said it is crucial that simplified language is used for all demographics of people. Scientific or academic ideas should not be used to complicate people on the ground, as a person's capacity will be getting in the way to take time to understand them.

9.6 Social Analysis – Survey of Student Renters in the ACT

9.6.1 Purpose

A survey was conducted to learn about student renters' home energy use and their willingness to adopt proposed load shifting strategies.

9.6.2 Methodology

The survey was tailored to an audience who met the following criteria:

- Rent a detached home, townhouse, flat/apartment or live on a university campus,
- Are aged 18-25,
- Attend one or more of the following ACT tertiary education institutions:
    - Australian National University,
    - University of New South Wales (ACT Campus),
    - Australian Catholic University,
    - University of Canberra.

9.6.3 Results

The survey was undertaken during the winter of 2025. It began with 8 demographic questions including questions to ensure the respondent was indeed a student and renting their accommodation, then 15 scoping questions to understand the student renters' living situation and the appliances available to them, 8 questions on the respondents' perspective on renewable energy, and 6 questions about the feasibility of the respondent being able to implement a range of possible demand-shifting solutions presented to them. The survey questions are attached in Appendix 9.

45 responses were received, however 21 were not viable due to being incomplete or outside of target demographic therefore 24 responses were included in analysis.

<u>Survey results: Part 1 – demographics</u>

The following demographic questions aimed to understand the background of the respondents.

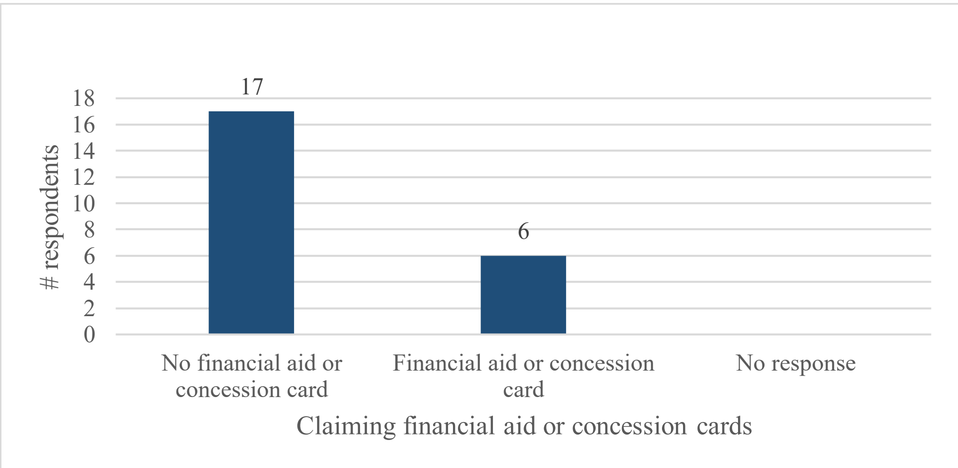

Figure 7: Survey question: Does the respondent claim financial aid or own a concession card/s?

<u>Survey results: Part 2 – scoping</u>

The following questions aimed to understand the situation each respondent was in including their housing situation and the appliances located and used in their household. The intent is to gain further background that will inform the effectiveness of the solutions.

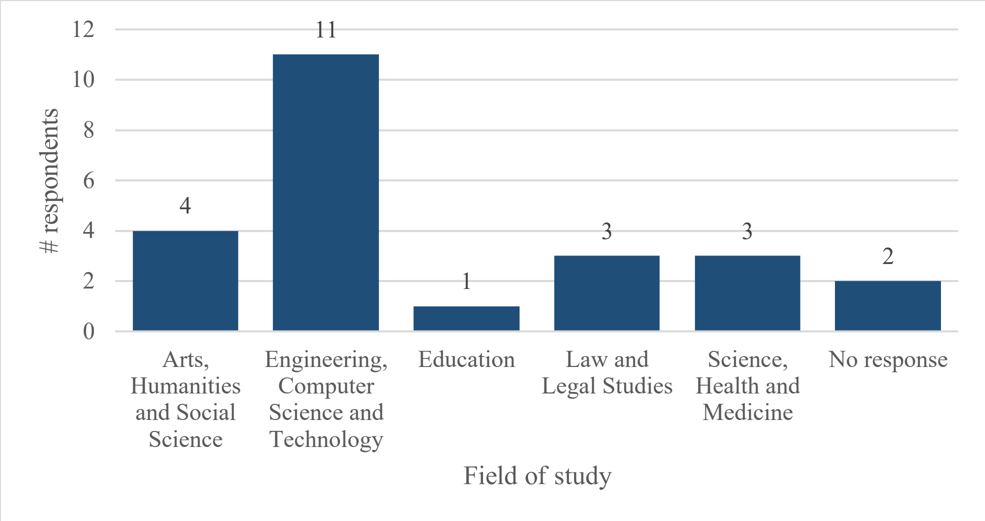

Figure 8: Survey question: What is your field of study?

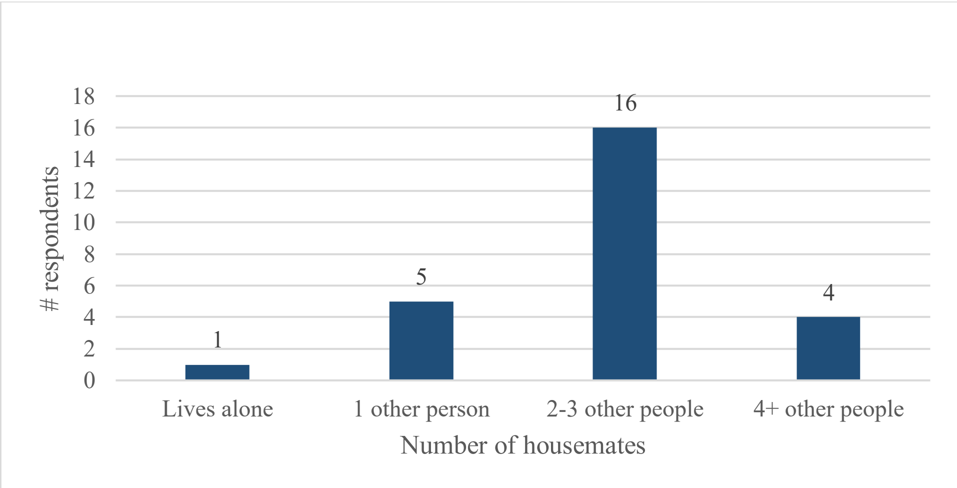

Figure 9: Survey question: How many housemates do you have?

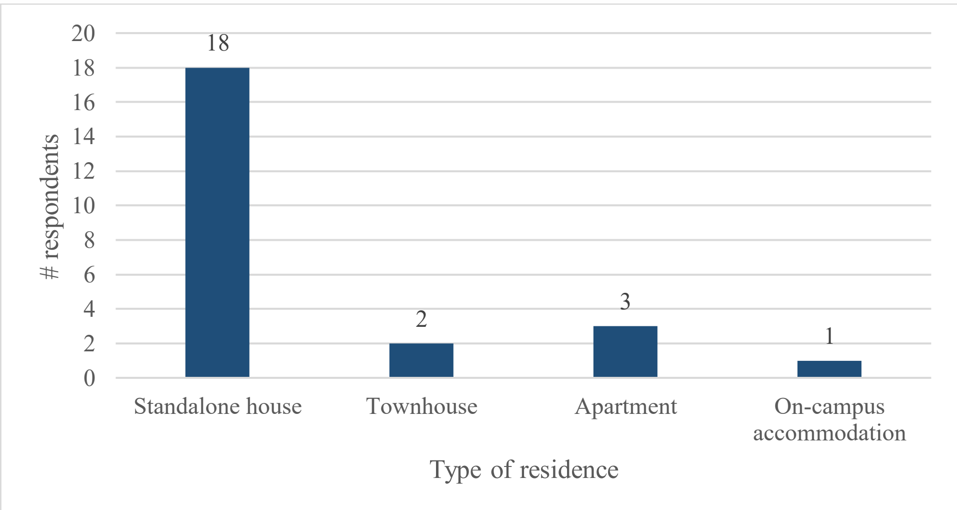

Figure 10: Survey question: What type of residence do you live in?

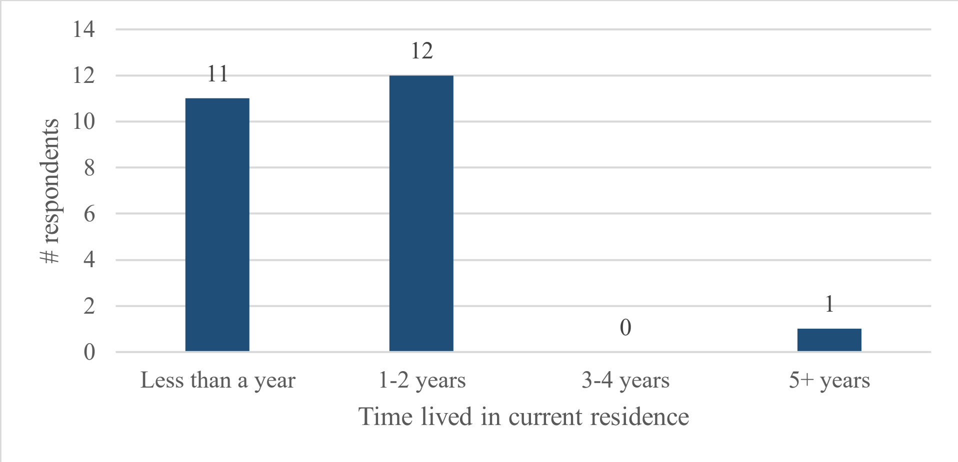

Figure 11: Survey question: How long have you lived in your current residence?

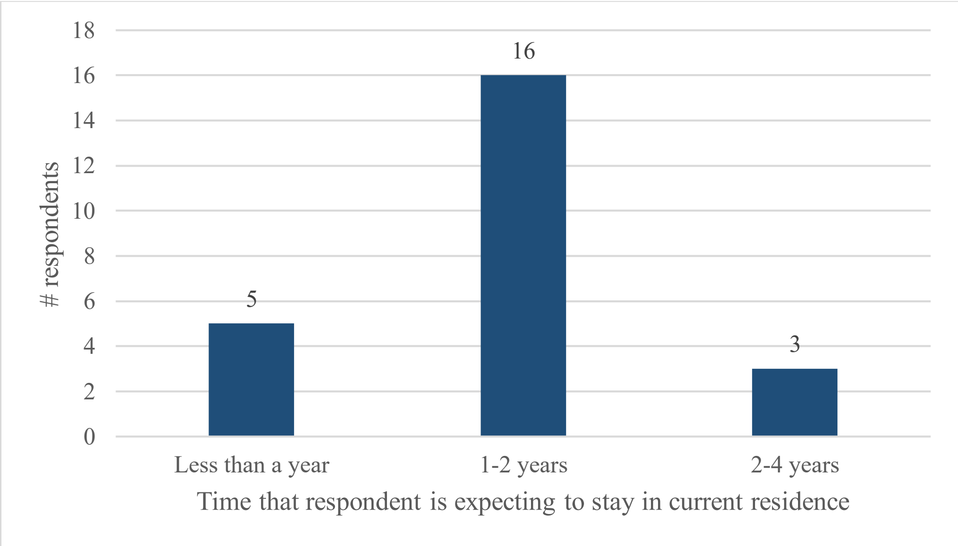

Figure 12: Survey question: How long are you expecting to stay in your current residence?

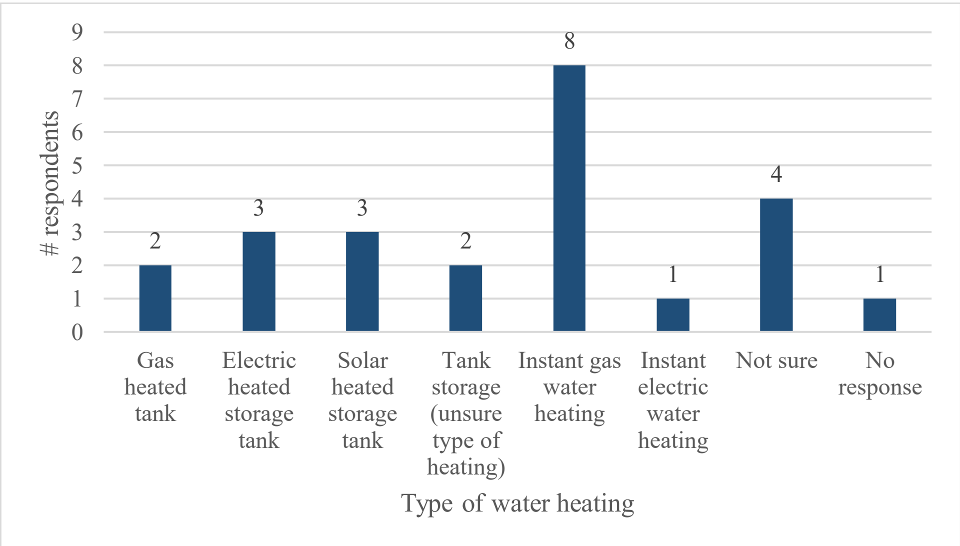

Figure 13: Survey question: What type of water heating is in your residence?

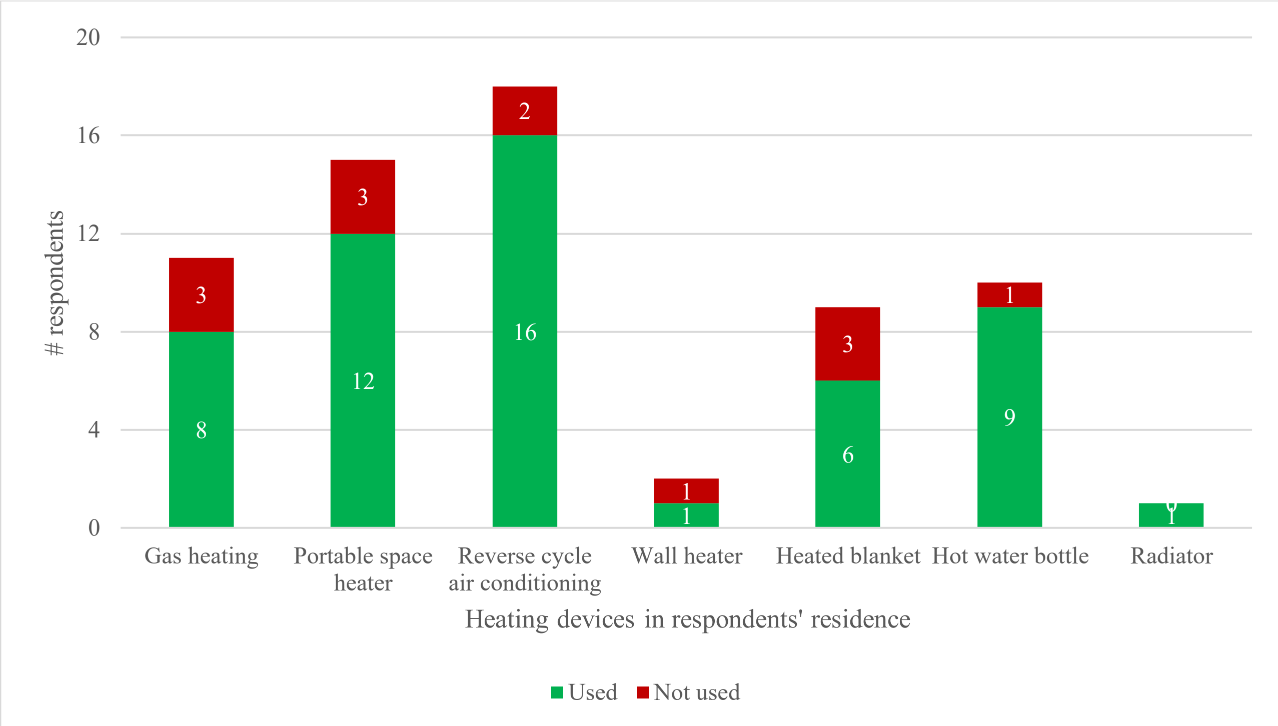

Figure 14: 2 survey questions combined: "What heating devices do you have in your residence?" And "What heating devices do you use?".

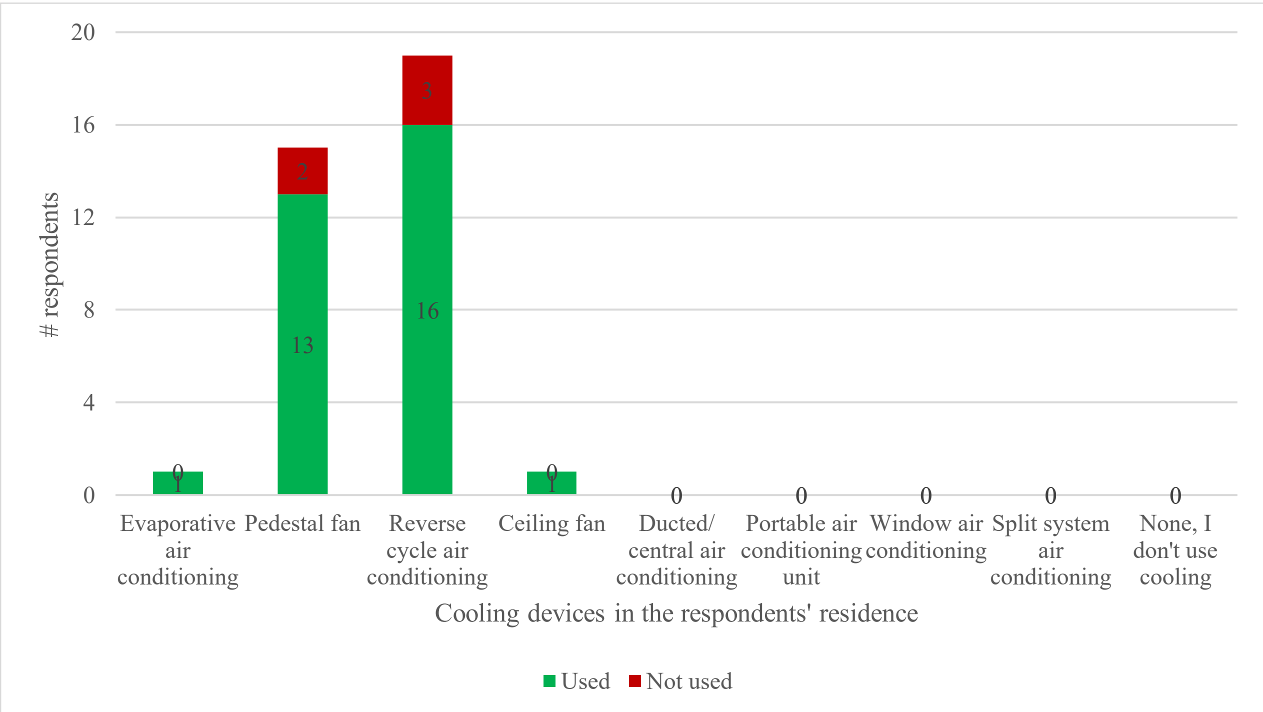

Figure 15: 2 survey questions combined: "What cooling devices do you have in your residence?" and "What cooling devices do you use in your residence?"

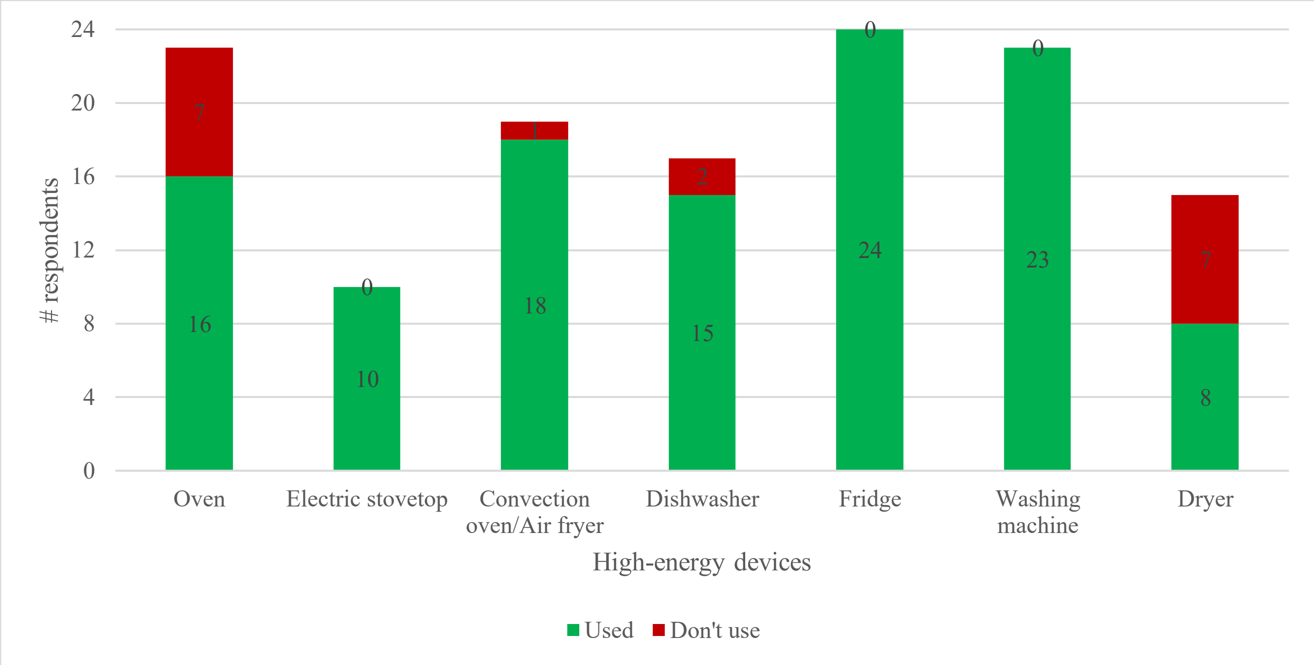

Figure 16: 2 survey questions combined: "What high-energy devices do you have in your residence?" and "What high-energy devices do you use in your residence?"

Respondents were asked about the renewable technologies they currently have in their house. The intent of this question is to understand whether there is high uptake already among student renters' residences which will impact the viability of some solutions that the report may recommend. One person responded to 'Other', saying 'Double glazing'.

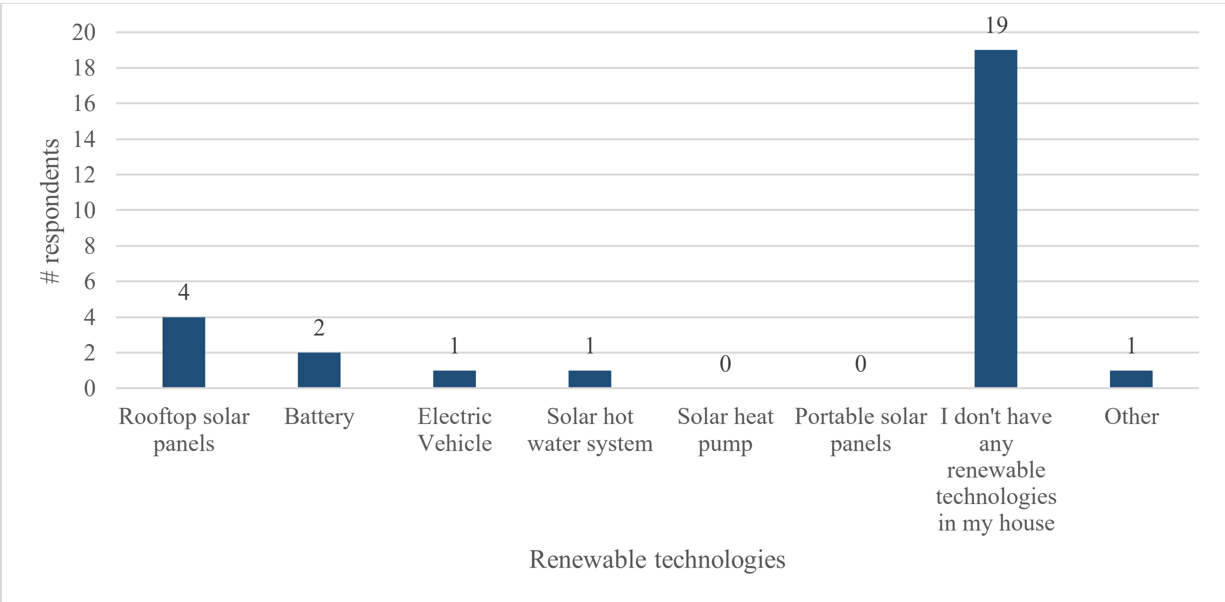

Figure 17: Survey question: What renewable technologies do you currently have in your house? Select all that apply.

<u>Survey results: Part 3 – perspective</u>

The intent of these questions is to understand the viewpoint of each respondent, including to understand if they are or are not willing to engage with some types of solutions compared to others.

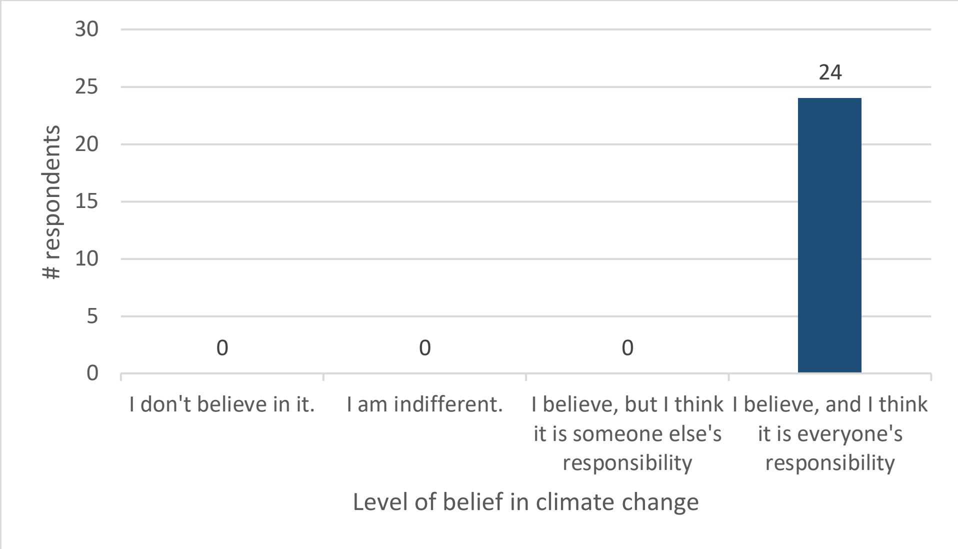

Figure 18: Survey question: Do you believe in climate change?

Respondents were asked about their highest priority is regarding increasing renewable energy usage in their household. This question intends to understand the motivations behind the respondents' interest in using renewable energy, which can be used to inform the incentives that can be used to increase uptake of solutions. One respondent said 'Other'. This response was "Both saving money and reducing climate change. Win / win situation no?".

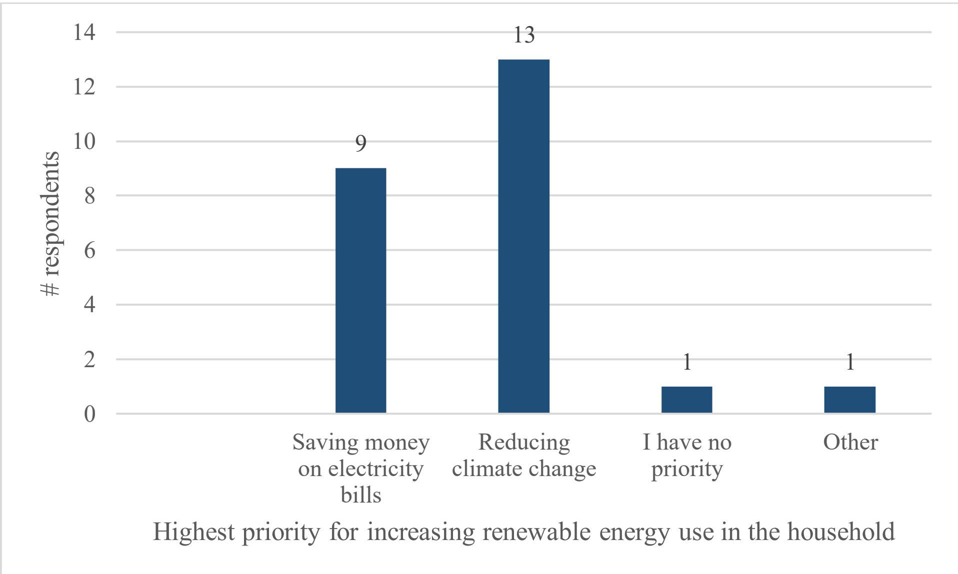

Figure 19: Survey question: What is your highest priority about increasing renewable energy usage in your household?

Respondents were asked about their biggest concern about increasing renewable energy usage is in their household. The intent of this question is to understand what might be holding student renters back from engaging with the renewable transition. Two responded with 'Other'. These responses were "No concerns. I was under the impression grid instability is increased through lack of sustainable energy sources.", and "In rental, cannot engage with renewables".

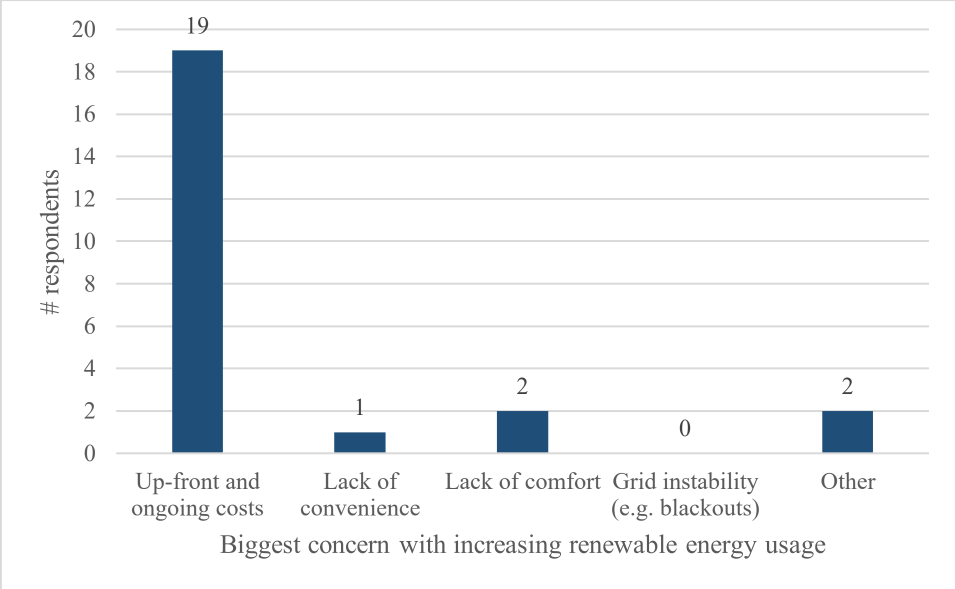

Figure 20: Survey question: What is your biggest concern about increasing renewable energy usage in your household?

Respondents were asked about their willingness to shift their energy usage to time when renewable energy is more available. The intent of this question is to further understand what may be preventing student renters from engaging with renewable energy, particularly from the lens of demand shifting.

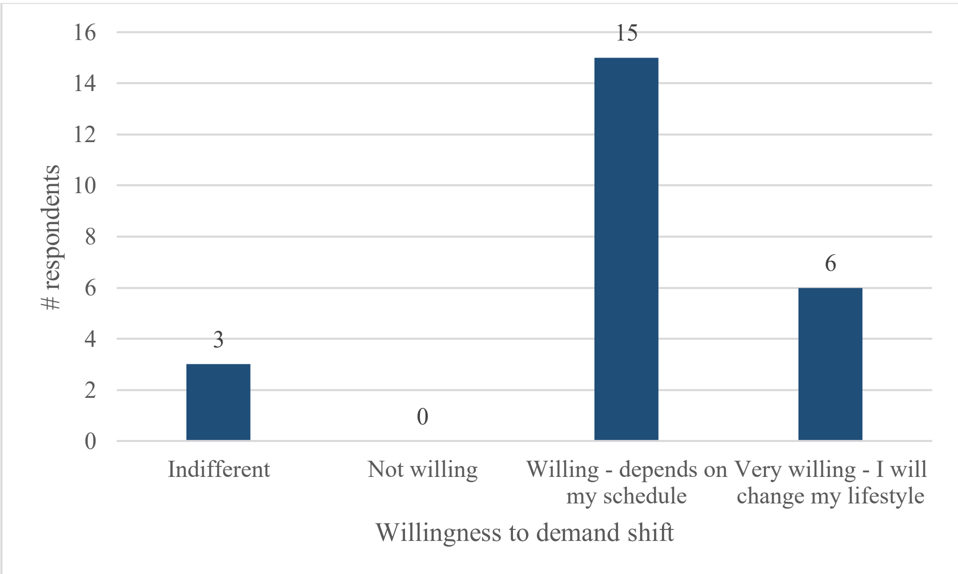

Figure 21: Survey question: How willing are you to shift your energy usage to time when renewable energy is more available?

Respondents were asked about how much they understand the charges and information on their electricity bill. The intent of this question is to understand if student renters are informed about their energy usage and generally energy literate, or if some of their hesitancy for engaging with the energy transition is due to a misunderstanding or lack of information.

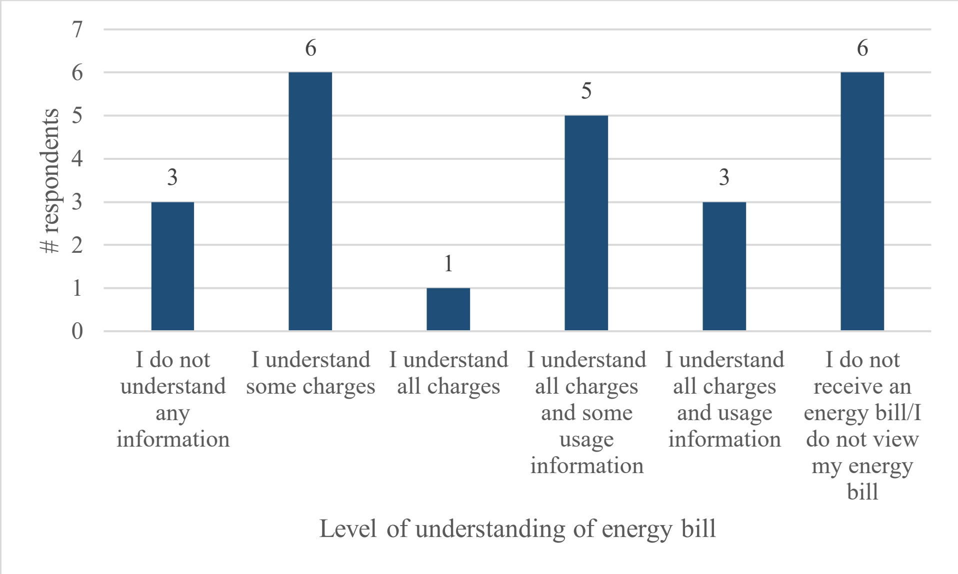

Figure 22: Survey question: How much do you understand the charges and/ or information on your energy bill?

Respondents were asked about the energy saving techniques they use. The intent of this question is to understand their current actions taken towards reducing or shifting energy usage, to understand if what behaviours are already happening and where our research can fill any gaps. It is also useful to understand what sort of behaviours student renters find convenient in their current lives. It is noted that there were two respondents who chose to provide a text answer in the 'Other' option. These responses were "Only drying clothes on a line, not using the dryer" and "Ice caving in the crib during winter to avoid heating bills at all costs!".

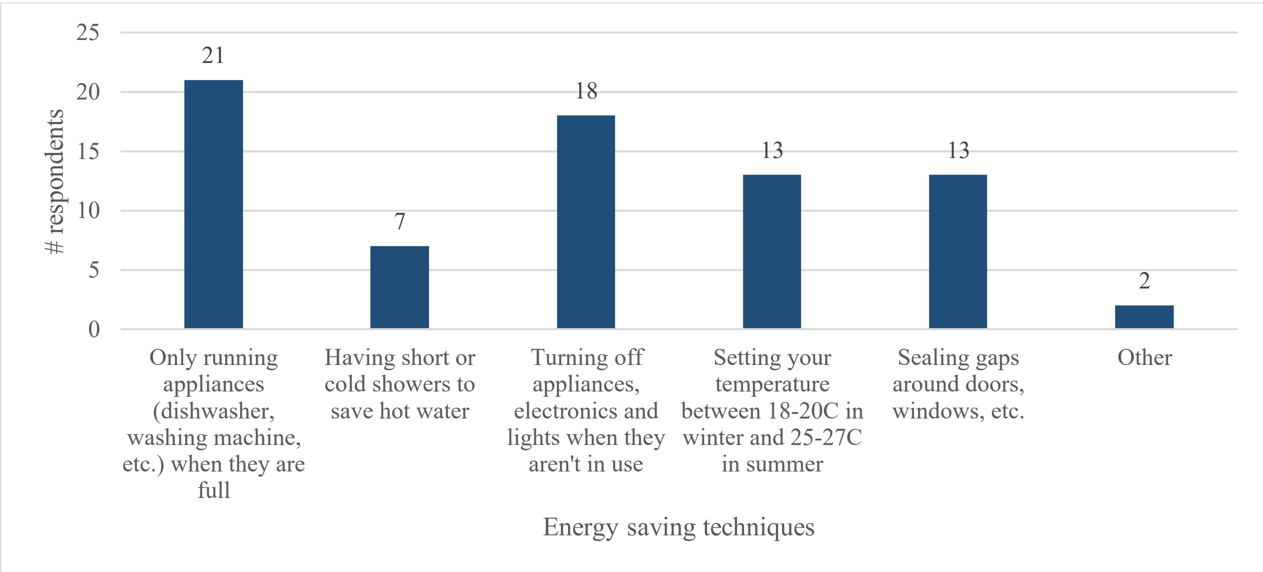

Figure 23: Survey question: What energy-saving techniques do you currently use? Select all that apply.

Respondents were asked about the times they were generally home during the week. Specifically, they were asked "How many days of the week are you typically home during the following times?" The options were 7am-9am, 9am-1pm, 1pm-6pm, 6pm-9pm, and All day." We then averaged the number of days each person was at home for each time period to produce the following graph. Note that it was assumed that people would be home from 9pm-7am. The intent of this question is to understand how often the student renters are home during the day and therefore if they are able to engage in load-shifting activities during the middle of the day, or if our solutions will need to be remotely activated if students tend to be away from home during the day. Figure 24 demonstrates that that the average student is usually home early in the morning and in the evening which is expected. Specifically, the average student is home 5.5 days a week between 0700-0900 and 1800-2100. Furthermore, and as expected, the average student is often not home during the day, they are home only 2-3 days a week during the middle of the day (0900-1300 and 1300-1800).

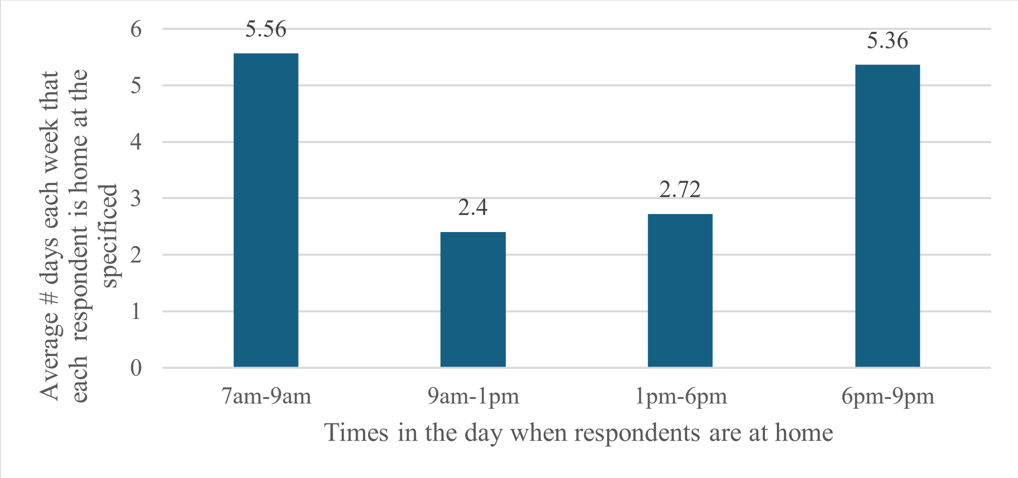

Figure 24: Survey question: How many days of the week are you typically home during the following times?

<u>Survey results: Part 4 – Feasibility</u>

The intent if the feasibility questions is to understand the opinion and willingness and ableness of respondents to implement specific solutions presented to them.

The respondents were provided with brief descriptions of each solution to help them understand what each involves. This is attached in Appendix 8.

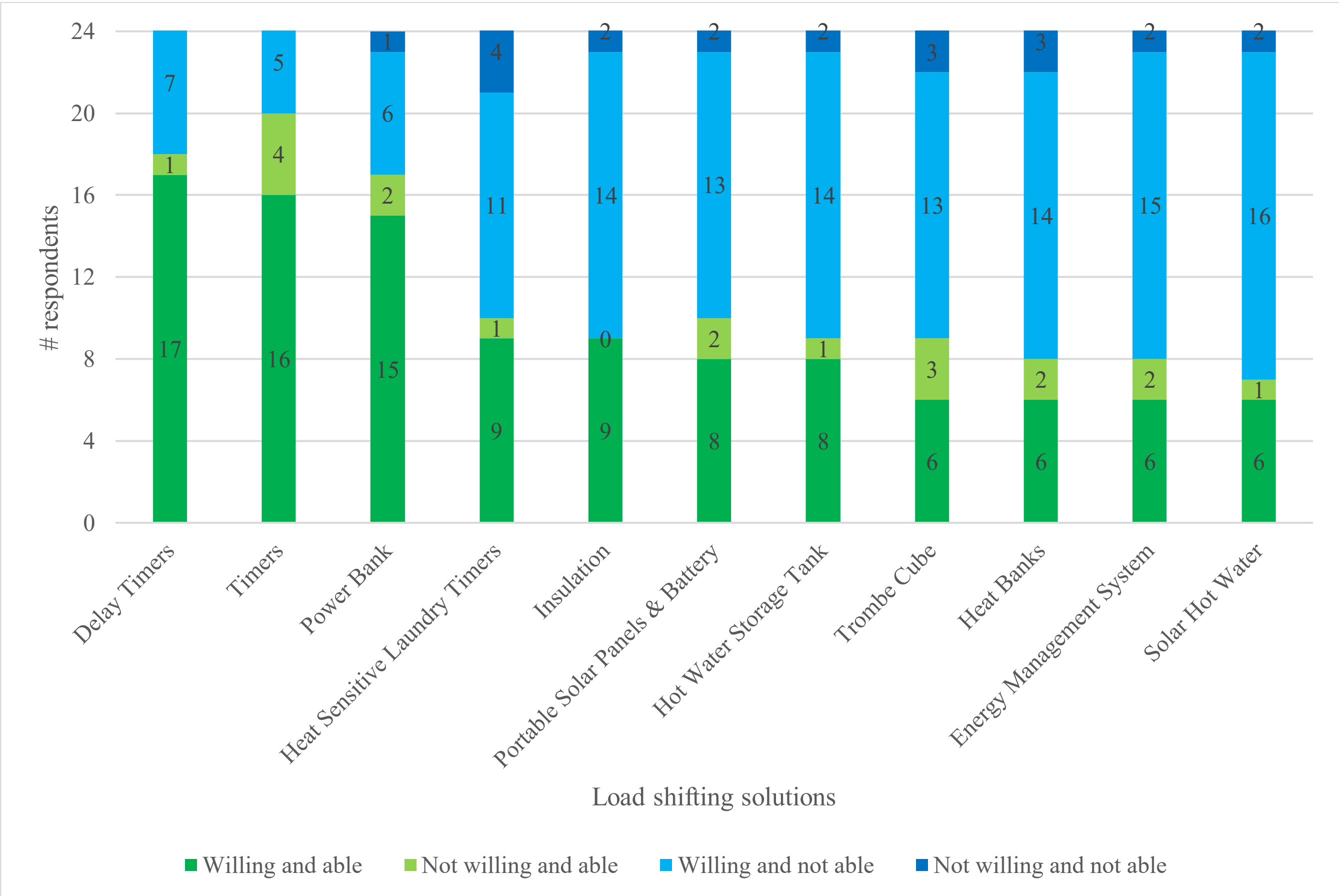

Figure 25: Survey question: Are you willing and/or able to use these solutions?

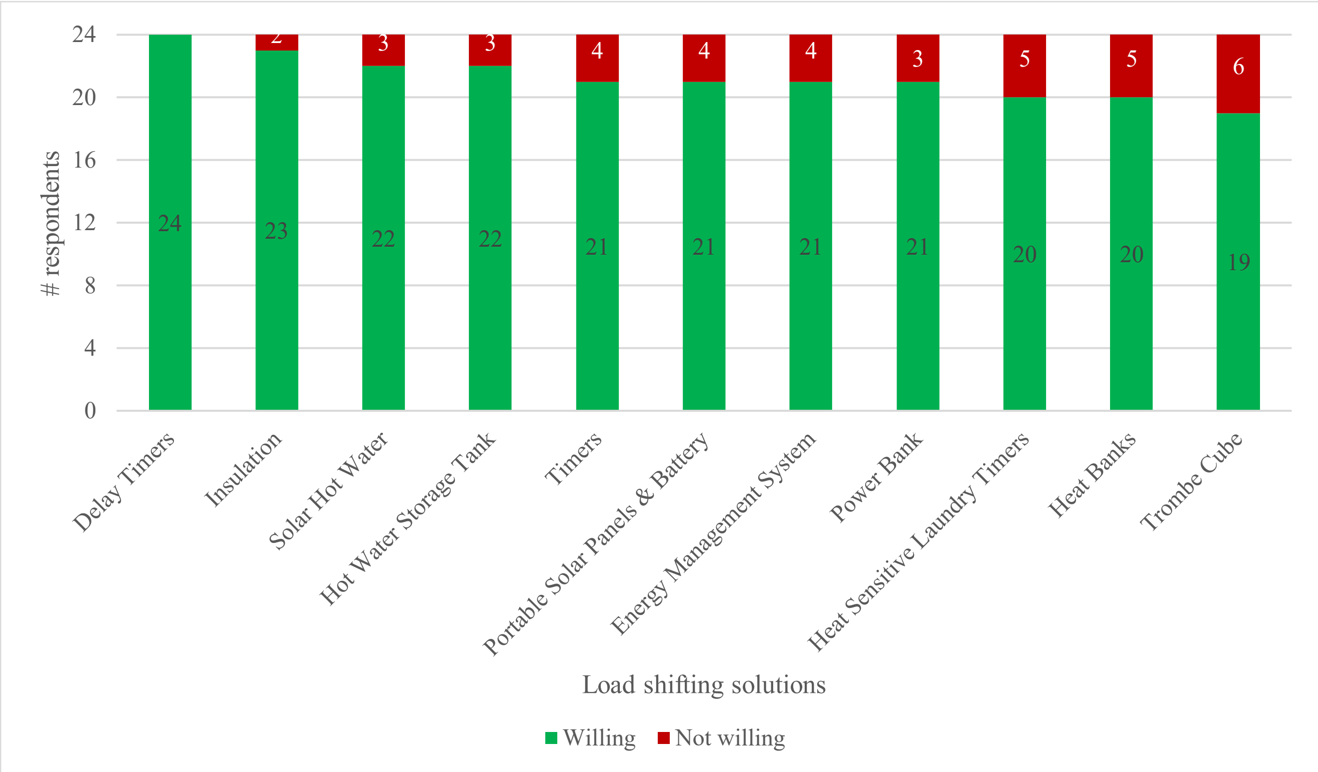

Figure 26: Survey question: Are you willing and/or able to use these solutions? Willing/Not willing results comparison only.

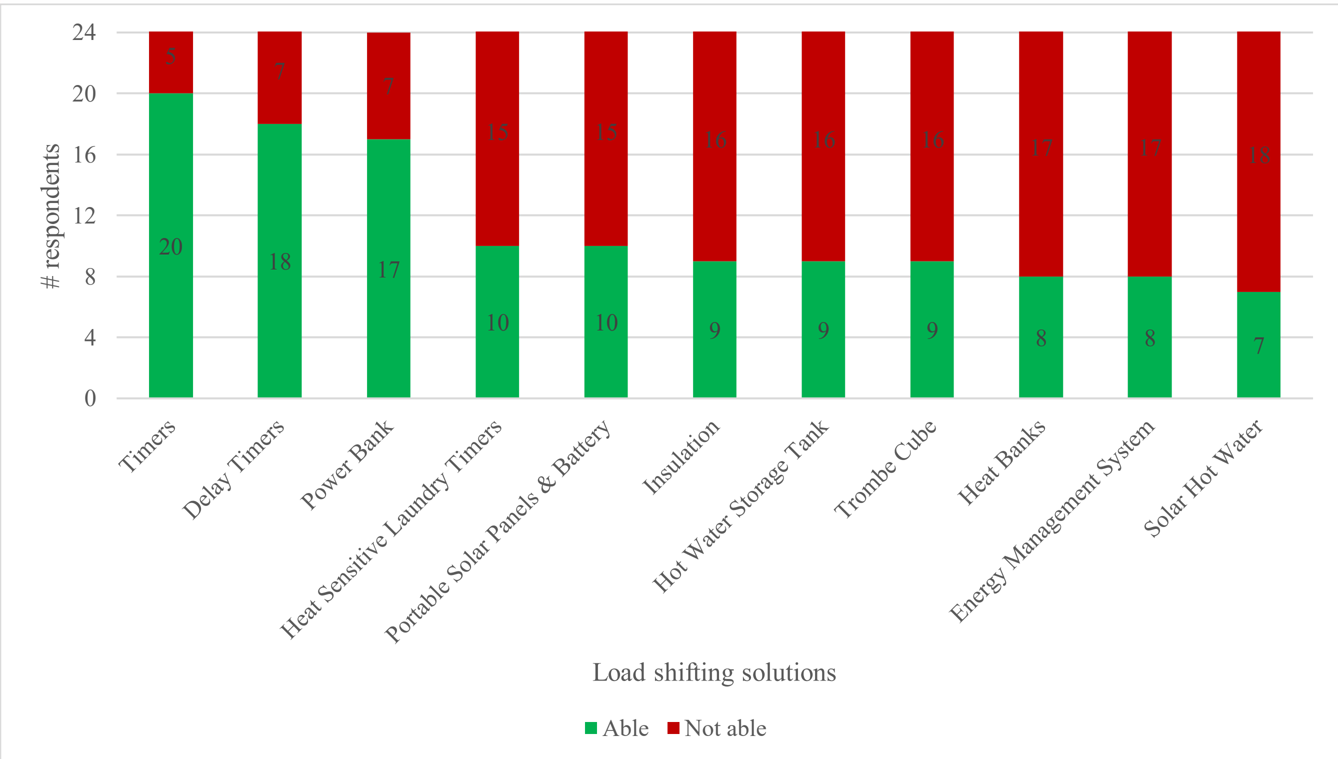

Figure 27: Survey question: Are you willing and/or able to use these solutions? Able/not able results comparison only.

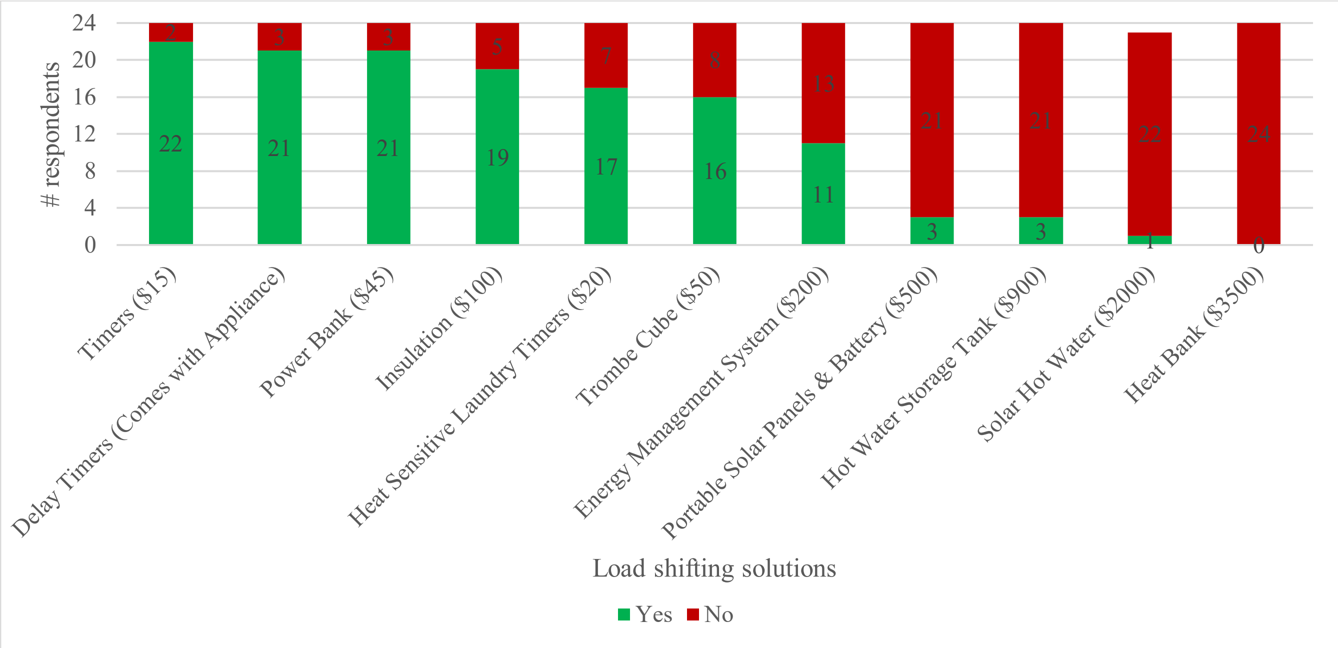

Figure 28: Survey question: Would you purchase these solutions based on the price?

Respondents were then asked to rank the solutions from 1-11 based on how likely they were to install and use these solutions. The intent of this question is to understand the solutions that the respondents are most willing to install and buy. The numbers are derived from a calculated weighted average rank.

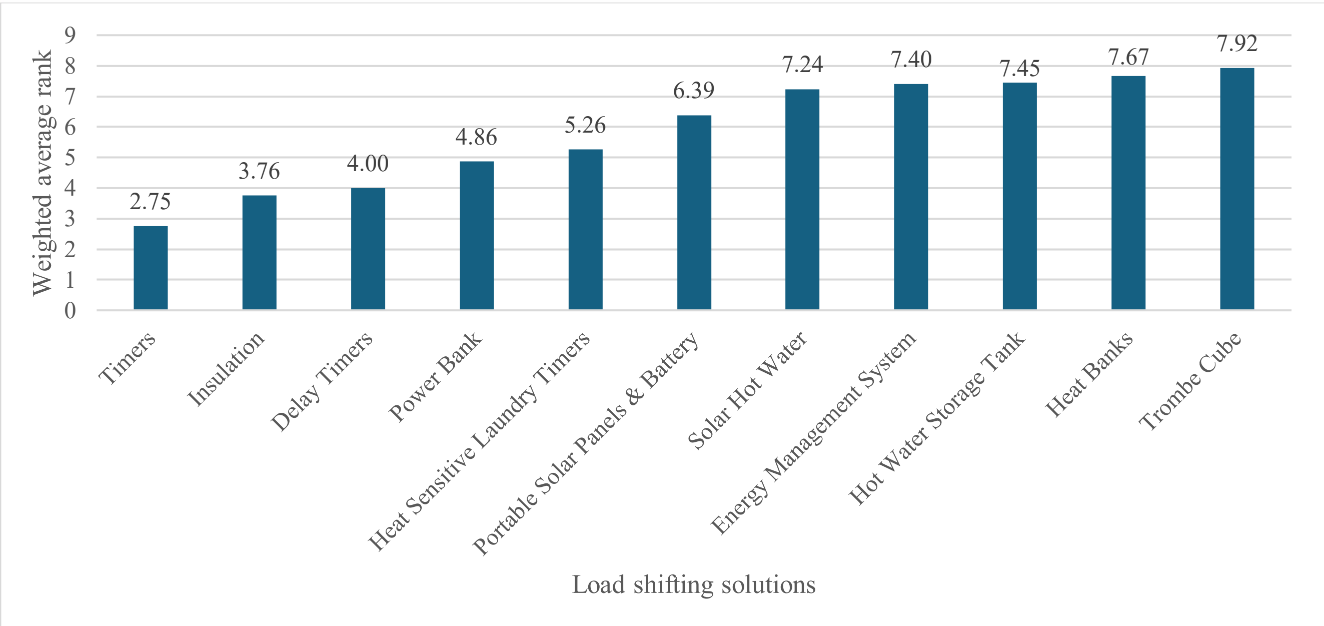

Figure 29: Survey question: Rank how likely you are to install and use these solutions?

9.6.4 Outcomes

Part 2 - scoping

Most respondents reside in a standalone house and live with two to three other people who are usually friends. Given that 23 of the 24 respondents have lived in their residence for less than two years, and that 21 said they would be leaving their residence within two years, it can be reasonably assumed that the average student renter in the ACT is spending less than four years in the same house before moving. It can therefore be inferred that solutions should be easy to remove and re-installed at another house given the high frequency at which student renters move between rental houses.

The respondents had five main heating devices in their houses, gas heating, portable space heating, reverse cycle air conditioning, heated blankets, and hot water bottles. Most of these were also being actively used by the respondents. The respondents had two main cooling devices, a pedestal fan and reverse cycle air conditioning. Most respondents with these devices also actively use them. These high usage rates of these items suggest that it will be important for the demand shifting solutions to help student renters to shift, where possible, the use of these household appliances to times of higher renewable penetration.

Respondents were asked about the high-energy devices in their homes and if they used them or not. While most houses had these high-energy devices (such as ovens, electric stovetops, convection over/air fryer, dishwasher, fridge, washing machine, and dryer), half of respondents did not use their dryers (where it can be assumed these respondents air dried their clothes on the line) and a third of those with ovens did not use them. Therefore, it is important for the solutions to focus on shifting the demand of those higher-use appliances to have greater impact, and less focus on those lesser-used items.

Part 3 - perspective:

All respondents believe in climate change, and most are willing on some level to shift their energy usage to times of high renewable generation. Their main concern about increased renewable energy usage in their household is cost, and the main priorities with increasing renewable energy usage in their house is split between saving money and reducing the effects on climate change.

The respondents were knowledgeable about their energy bills and usage charges. This implies a high level of energy literacy and therefore it can be implied that student renters will be fairly interested and able to understand the impacts of our proposed solutions, which will drive higher uptake.

The respondents engaged in several energy saving techniques, particularly turning off appliances when not in use, only running appliances when they are full, being conservative with heating and cooling temperatures, and sealing gaps around doors and windows. This indicates a strong interest already among student renters in their willingness to engage in demand shifting and energy reduction behaviours, so they are likely to be further interested in engaging with the solutions identified in this report.

The data shows that these respondents are not home very often during the day, so they won't be home to manage their energy usage, such as turning the washing machine on at 1pm when the sun is shining. This means that our solutions should be focused on those that can be remotely operated from an app or similar device as student renters are often not home to manually use load shifting solutions.

Part 4 – Feasibility - Willingness and ability to adopt our proposed concepts

Most respondents preferred to install and use power point timers, insulation, delay start appliance, and power banks. These solutions were also the most preferred when the respondents were asked which of the solutions they would implement given a price estimate. This aligns with the other analyses performed.

Timers, delay timers and power banks were the solutions that respondents were most able to implement. Insulation was ranked lower, likely because it would require more effort to implement than the former three solutions and is more expensive. This is good to understand for the way that policy solutions can be implemented to ensure uptake while remove barriers such as high cost or difficulty transporting the solutions (e.g. insulation) home.

The respondents were willing to implement all solutions, with Delay Timers and Insulation the highest rated. The lowest rated solutions, Trombe Cube and Heat Bank, were likely rated lower because the respondents were were unfamiliar with the technology.

Summary

The survey indicates that four solutions were clearly preferred by respondents – delay timers, power point timers, power banks and insulation. These solutions align strongly with the four best solutions that the verification process (outlined in Section 8) produced.

These results are very encouraging; however, it should be noted that 24 responses are not representative of the ACT student renter population.

10 DISCUSSION

The energy data model shows that all shortlisted solutions can shift appliance's energy consumption with proactive participation and involvement from the tenant. The levels of involvement can vary, and automated systems will decrease the amount of active engagement needed from the renter. The model also shows that the amount of electricity that can be shifted is highly dependent on type of appliances and frequency of usage which varies by household. Owning efficient appliances will support electricity consumption reduction. Having flexible schedules will better facilitate a renter's ability to move their consumption to high renewable energy generation times.

The biggest energy shifting potential comes from the insulation package, followed by the delay start appliances, as they target the heaviest electricity consumers: HVAC, dryers and dishwashers. Shifting HVAC is most feasible when insulation is higher because the setpoint temperatures can be maintained over longer periods of time without requiring more energy, while maintaining the tenant's comfort.

Policy analysis aims to identify the best policy solutions that can be applied to our four solutions to increase the rate and total uptake of these solutions. Policy analysis shows that three of the four solutions would significantly benefit from target policies to increase their uptake among student renters. Specifically, timers, power banks, and the insulation package would benefit from a procurement-style policy whereby the government would purchase these solutions in bulk from an appropriate supplier, and distribute to student renters at no cost. The policy analysis found that uptake of delay timers would not be significantly increased with a similar policy as they are embedding into dryers and washing machines.

Timers and power banks are small and portable solutions which means that are easy to distribute in large volumes to student renters. By distributing these as no cost at university campuses, and checking student IDs to ensure they go to students only, students can easily access these solutions, which will increase uptake.

The insulation package is bulky and therefore would need to be delivered to the student renters' homes. Therefore it would be best for the government to purchase insulation packages in bulk and distribute to student renter's homes via a free delivery service. To be used, the insulation package will take time to be installed. The cost of paying an installer to install these for free, particularly the thermal curtains and pelmets, would be expensive. However the installation is fairly simple so it can be expected that the student renter could install the insulation package themselves.

Economic analysis showed that three out of four solutions are economically viable investments for renters that will produce an economic 'payback' over their lifetime. Power banks were deemed as not viable in both methods of analysis and are therefore not recommended.

Whilst two analysis methods were provided, the required uptake method is deemed as most significant in this analysis. Renters are in unique positions in that while they may have high concern for energy usage and a strong willingness to participate in the energy transition, this is negated by their capacity to do so, in terms of a multitude of factors but particularly financial. Due to this the most highly recommended solution is power point timers, over the insulation package, which had the highest pay back over its lifespan.

This is further supported by another aspect of renter's low capacity, their limited disposable income compared to other groups. Power point timers have the lowest upfront cost, reducing the barrier to entry for purchase for renters compared to larger purchases such a delay start machines, despite their larger long-term payoff. This is further compounded by other factors such as the lifespan of products and the simplicity of use. Whilst solutions such as delay start timers and insulation packages may have strong economic viability, they may have more barriers to entry with regard to the renter landlord relationship than the transportable power point timer. Additionally, the benefits of solutions with longer lifespans, making them more economically viable may be counteracted by students being less likely to stay in one home for extended periods of time and thus not taking advantage of the full lifespan of products. Further work in economic analysis should involve further stakeholder engagement regarding willingness to spend and additionally incorporating renters' incomes into economic analysis to further understand the economic viability of upfront purchasing.

The LCA shows a quantitative assessment of material impacts, which are directly related to the amount of materials used and the unit impacts of each material. While it concluded that power point timers and power banks have the least impacts due to their limited materials. Power banks as the most environmentally viable solution is consistent with the findings of the technical analysis, which concluded that power banks had the best load shifting capability but shift the least net amount of energy per year.

The insulation package had significant environmental impacts; however, it has significant load shifting capacity and results in the greatest amount of energy shifted per year. Thus, environmental impacts of the insulation package are deemed to be offset by the technical performance of the products. The high impacts of the insulation package are brought on by the production of cotton in the thermally backed curtains, which indicates that the overall viability of the solution will be improved if the cotton is replaced for other textiles such as flax linen or wool. [82]

The delay start appliances are the least environmentally viable solution because renters are likely to already have these appliances in their home, and the high environmental impacts do not justify replacing their existing appliances for appliances with delay start functions. As such, delay start appliances are an important consideration when renters are furnishing their homes or replacing broken goods, but they are not recommended if renters already have the appliances they need. Existing appliances that do not have a delay start functionality are typically compatible with power point timers.

Mary and Mark both identified concern as a motivator to participate however a student's capacity becomes a barrier. Additionally, they agreed on our solutions, which sparked a conversation about the Renter-Landlord power dynamic and how this has constrained our requirements to produce 'simple' solutions. Throughout the interviews, both SMEs verified our stakeholder requirements that we created to address these challenges and produce solutions that would empower student renters. Mary identified our project as a pragmatic approach and that future works should also focus on renter-landlord solutions, infrastructure, and societal shifts. Everyone has a collective responsibility to ensure the energy transition is equitable and inclusive. This responsibility also extends to creating equitable access to knowledge sharing and energy literacy. Easy to understand communication is crucial to ensure student renters are being included in the energy transition.

The survey data showed that the four best solutions as identified through our requirements and criteria analysis also came out on top in the survey results. Respondents were most willing to implement timers, delay timers, power banks, and the insulation package, although insulation was rated lower by respondents when asked about how able they were to implement the solution, assumingly because it is a large exercise to find, purchase and install the insulation items. All respondents said yes to "Yes I believe in climate change, and it is everyone's responsibility." This shows that they do all care about the emission reduction, however may not be able to implement them due to limited capacity.

11 FINAL RECOMMENDATIONS

The analysis shows that student renters in the ACT face challenges to participating in the renewable energy transition, such as a lack of property ownership, limited control over household changes, financial constraints and information gaps. However, there are several practical, renter-controlled measures that are low cost and can meaningfully shift energy to periods of renewable generation, thereby lowering emissions, electricity bills and stress on the electricity grid. These include the proposed insulation package (including curtains, door snakes, room dividers and temporary double glazing), delay start timers, portable power banks and power point timers. Renters are crucial players in Australia's grid decarbonisation but are under-resourced. To achieve an equitable and long-lasting impact, action must be taken by each of the partners and stakeholders in a well-coordinated manner. The following recommendations tie in technical, economic, policy, social and environmental insights from the research, analysis and survey. Broad recommendations ACT Government programs and tertiary institutions should encourage the use of simple, portable load-shifting devices to renters. Power point timers were a highly ranked solution in technical, economic and social lenses as they are inexpensive, easy to use, portable and do not need landlord approval. Therefore, the distribution of timers to renters at no cost or at a subsidised cost, paired with information on how to optimally use it for load shifting, will be beneficial. Where possible, appliances with delay-start features should be promoted for their load shifting capability. Increasing education and running campaigns could expand knowledge on this often-under-utilised feature. Rebates that are targeting landlords could help encourage replacing old appliances with upgraded delay-start applicable appliances.

Portable insulation measures (thermally backed curtains, temporary double glazing, door snakes, room dividers, rugs) are affordable ways to maintain heating and cooling setpoint temperatures and assist with load-shifting. Universities, organisations, and communities could partner with Australian suppliers to provide insulation starter kits, with subsidies available for students.

Ensuring equity in the energy transition is key. Education campaigns should come from trusted intermediaries, such as universities, subject matter experts or independent groups rather than energy retailers. The messages should be clear, simple, action-orientated and convey tangible benefits such as improved comfort or reductions in electricity bill pricing. Governments must continue working towards equitable gas network decommissioning, target rebates and grants for landlords and renters aimed at electrification and energy efficiency improvements. Policies should prioritise creating safeguards to ensure costs do not flow onto the tenants via rent increases.

11.1 STAKEHOLDER-SPECIFIC RECOMMENDATIONS

Relevant recommendations for each stakeholder are outlined in Table 13.

Table 13: Stakeholder-specific recommendations

Student Renters	• Where feasible, invest in portable, renter-friendly load shifting solutions as there are several feasible, effective options (e.g. timers, power banks, curtains, etc.)
	• Where possible, automate appliances using timers and encourage buy-in from the whole share house
	• Take advantage of free or subsidised programs (e.g. ACT Sustainable Home Advice and free Home Energy Assessments)
	• Recognise that adopting load shifting solutions will support the transition by
	    o Matching energy supply and demand to reduce stress on grid infrastructure
	    o Making better use of renewable energy generation as opposed to fossil fuel consumption
	• Load shifting solutions can also deliver electricity bill reductions when on a ToU tariff structure

Government & Private Sector	• Provide clear, renter-focused education campaigns to show renters low-cost solutions and their benefits, highlighting that the energy transition can provide them with positive benefits • Recognise renters as a long-term investment in the green energy transition as the renters of today may be future homeowner's and building early engagement with sustainable technologies can influence mindsets and adoption rates in the future. • Subsidise or distribute low-cost solutions to renters, such as timers, insulation and power banks • Increase funding for renter-orientated sustainability programs and ensure access is equitable • Ensure landlord policies prevent rent increases that are linked to sustainable upgrades
Government Initiative Program Delivery Organisations	• Expand engagement and outreach by communicating with students directly on campuses • Deliver renter-targeted incentives • Encourage landlord participation without passing costs to tenants and engage landlords directly with education campaigns
Tertiary Education Institutions / Subject Matter Experts	• Technological development can reduce capital cost which supports economic feasibility. In turn, this will make solutions more accessible and feasible for student renters. • Explore and share renter-focused sustainability advice into student services, residence life and classes where appropriate. • Work on translating the technical expertise into accessible and clear advice that is easily understood by students and renters.
Community Organisations	• Share information about sustainability programs, like the home energy assessment, and renter-friendly load shifting solutions • Describe the practical benefits: cost savings, and comfort & wellbeing improvements, to increase buy-in and interest.

12 Statement on Generative Artificial Intelligence

Generative AI was not used at any stage of this report.

13 Statement on Ethics Committee Clearance

The ethical aspects of this research, specifically the survey and interviews with subject-matter experts, have been approved by the ANU Human Research Ethics Committee (H/2025/0330).

14 REFERENCES

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Appendix 1 QUALITY FUNCTIONAL DEPLOYMENT (QFD)

Renewable Renters QFD

Design Criteria & Attributes

Design Requirements		DC1 Electricity demand shifted from peak to off peak hours	DC2 Annual applicability	DC3 Proportion of renewable energy used in dwelling	DC4 Time taken to remove trace of solution	DC5 Size of solution	DC6 Time required to install solution and make it operational	DC7 Savings on user's electricity bill attributable to solution	DC8 Cost of implementation	DC9 Reduction in energy consumption	DC10 Time taken out of regular schedule to operate solution	DA1 Is the solution accessible to ANU students?	DA2 Will the solution require landlord approval to install as per the 'ACT Renters Book' (Residential Tenancies Act 1997)?	DA3 The solution must be compatible with Australian Standard power outlets (AS/NZS 3112) and standard household appliances	DA4 The solution should be compatible with standard operating systems (Windows, MacOS, Linux)	Requirements Importance Weightings	
The solution must shift demand to peak renewable energy production	R1.0	1														1	12.7%
The solution must be feasible for year-round application	R1.1		1													0.8	10.1%
The solution must increase the proportion of renewable energy used in households	R1.2			1												1	12.7%
The solution must be accessible to ANU students renting in the ACT	R2.0											1				1	12.7%
The solution must not interfere with the integrity of the dwelling	R2.1				0.4											0.6	7.6%
The solution must be able to be installed and removed by renters	R2.2				0.6											0.4	5.1%
The solution must be transportable/moveable throughout the lifetime of the product	R2.3					1										0.3	3.8%
The solution should reduce the cost of electricity for users	R3.0							0.7								0.6	7.6%
The solution should be inexpensive to implement	R3.1								1							0.6	7.6%
The solution should not increase overall energy cost from baseline	R3.2							0.3								0.2	2.5%
The solution must not increase overall energy usage from baseline	R3.3									1						0.3	3.8%
The solution must not require the landlord's approval to install	R3.4												1			0.4	5.1%
The solution should be easy to understand and use	R3.5						1							1	1	0.4	5.1%
The solution should not inconvenience renters' daily routines	R3.6										1					0.3	3.8%
Design Criteria Importance Weights		0.127	0.101	0.127	0.061	0.038	0.051	0.061	0.076	0.038	0.038	0.127	0.051	0.051	0.051		
Design Criteria Importance Rankings		1	4	1	6	12	8	7	5	12	12	1	8	8	8		

Key: 1 = highest rank and most important

Appendix 2 SYSTEM FUNCTIONAL BREAKDOWN

Function	***F1.1 Receive (and Store) Renewable Energy***
Inputs	**Energy [I1:1]**
Outputs	**Renewable energy within household system [IC1.1]**
Description	**Energy is received and if required is transferred to a storage system.**

Function	***F1.2 Renters Alter Behaviour***
Inputs	**Renter [I1:3]**
Outputs	**Renters change energy usage behaviour [IC1.2]**
Description	**Renter makes behaviour change in use of energy.**

Function	***F1.3 Use Received (or Stored) Renewable Energy***
Inputs	**Renewable energy within household system [IC1.1]** **Household Appliance [I1.2]** **Renters change energy usage behaviour [IC1.2]**
Outputs	**Energy Usage Shifted [O1.1]**
Description	**Renter shifts energy usage to consume renewable energy.**

Appendix 3 OTHER PRELIMINARY LOAD-SHIFTING CONCEPTS

Solution	**Benefits**	**Drawbacks**
Portable solar panels	Can utilise own solar generation and participate in load shifting Portable and rental friendly	Requires a battery and integration technologies Expensive
Slow cookers	Exclusively shifting to peak periods Low effort for renters to implement if used Portable throughout moves	High upfront costs for renters Potentially big change in lifestyle/behaviour based on meal changes required
Trombe cube	Passive heating device	Low technological readiness level
Heat-sensitive reminder for laundry	Little change to daily routine	Conceptual idea Not technologically ready Low impact

Renter-landlord solutions (in which joint involvement is required):

Solution	**Opportunities**	**Drawbacks**
Solar-powered water heater	Reduces reliance on grid-supplied electricity or gas for water heating Environmentally friendly Increases property value	High initial cost for purchase and installation Performance is dependent on the weather conditions May require a backup system for use in inclement weather
Water tank and heat pump	Water heating costs around 15% of $4,000 average energy bill each year which is $600. Heat pumps use 60% less electricity more efficient than instant electric heaters, so that reduces running costs by $360 a year.	Takes up space inside or outside the house. Expensive. The tank can run low so it takes a while to refill and reheat.

		Estimated yearly savings: $360
Heat banks / Electric thermal storage	Great load shifting capability Not that useful in the winter Self-contained and can be installed anywhere Little or no maintenance required	Electric in-slab storage heating because when poorly implemented they are extremely inefficient Often large in size May need landlord approval Expensive ($3,000-$4,000)
Wall and ceiling insulation upgrades	More significant insulation benefits	Expensive Difficult to retro-upgrade
Reverse cycle air conditioning	Captures heat from outside and transports in inside which is more efficient at heating than creating heat from gas. Saves estimated $1172 a year for an average Canberra household. Improves value of house.	Needs landlord approval. Expensive upfront cost. Takes time to organise. Can have issues with installation. Does not specifically load shift, just reduce energy used in peak demand times. But they can pre-cool or pre-heat a home during solar-output hours before the peak times begin.

Appendix 4 REQUIREMENTS SCREENING MATRIX

Performance Requirements

Solution Concept	**Requirement and Weighting**		
	R1.0	**R1.1**	**R1.2**
Insulation Package	**0**	**0**	**0**
Timers	**1**	**1**	**0**
Heat Sensitive Laundry Timers	**-1**	**1**	**-1**
Delay Start Appliances	**1**	**1**	**0**
Portable Solar Panels with a Battery	**1**	**0**	**1**
Behaviour Change	**1**	**1**	**-1**
Slow Cooker	**1**	**0**	**0**
Solar Water Heating	**1**	**0**	**1**
Hot Water Storage Tank	**1**	**1**	**0**
Heat Banks	**1**	**-1**	**0**
Trombe Cube	**0**	**0**	**1**
Energy Management System	**1**	**1**	**0**
Power Banks	**1**	**1**	**0**

Interface Requirements

Solution Concept	**Requirement and Weighting**			
	R2.0	**R2.1**	**R2.2**	**R2.3**
Insulation Package	**1**	**0**	**0**	**0**
Timers	**1**	**1**	**1**	**1**
Heat Sensitive Laundry Timers	**1**	**0**	**1**	**1**
Delay Start Appliances	**0**	**0**	**-1**	**0**
Portable Solar Panels with a Battery	**-1**	**1**	**1**	**0**

Behaviour Change	**1**	**1**	**1**	**1**
Slow Cooker	**-1**	**1**	**1**	**1**
Solar Water Heating	**-1**	**-1**	**-1**	**0**
Hot Water Storage Tank	**-1**	**-1**	**-1**	**-1**
Heat Banks	**-1**	**1**	**0**	**0**
Trombe Cube	**-1**	**0**	**1**	**0**
Energy Management System	**-1**	**-1**	**-1**	**-1**
Power Banks	**1**	**1**	**1**	**1**

Stakeholder Requirements

Solution Concept	**Requirement and Weighting**						
	R3.0	**R3.1**	**R3.2**	**R3.3**	**R3.4**	**R3.5**	**R3.6**
Insulation Package	**0**	**0**	**1**	**0**	**0**	**1**	**0**
Timers	**0**	**1**	**1**	**1**	**1**	**1**	**1**
Heat Sensitive Laundry Timers	**0**	**0**	**1**	**1**	**1**	**1**	**1**
Delay Start Appliances	**0**	**-1**	**1**	**1**	**1**	**0**	**0**
Portable Solar Panels with a Battery	**1**	**-1**	**1**	**1**	**1**	**0**	**1**
Behaviour Change	**0**	**1**	**1**	**1**	**1**	**0**	**-1**
Slow Cooker	**0**	**0**	**0**	**0**	**1**	**1**	**1**
Solar Water Heating	**1**	**-1**	**1**	**1**	**-1**	**1**	**1**
Hot Water Storage Tank	**0**	**-1**	**0**	**0**	**-1**	**0**	**1**
Heat Banks	**0**	**-1**	**0**	**0**	**1**	**0**	**0**
Trombe Cube	**1**	**0**	**1**	**1**	**1**	**1**	**-1**
Energy Management System	**0**	**-1**	**1**	**1**	**-1**	**0**	**1**
Power Banks	**0**	**0**	**0**	**0**	**1**	**1**	**0**

Appendix 5 ENERGY DATA ANALYSIS INFORMATION

The table below shows the appliances used in the energy data model, the applicability to each shortlisted solution, as well as their seasonal variation patterns. The wattage and frequency of use is listed. For further calculations, links to resources, detailed assumptions and the individual, concept-based analysis, please see the model at: Energy Data Analysis V1.0.xlsx.

	Solution / appliance applicability (Y if the appliance can be impacted by solution)				Seasonal Use				Frequency of use		Energy use		
Appliances:	PowerPoint Timers	Power Banks	Insulation Package	Delay Start Appliances	Summer	Autumn	Winter	Spring	Value	Units	Value	Units	Assumptions
Dishwasher	N	N	N	Y	Y	Y	Y	Y	7	cycles/wk	674	Wh/cycle	Energy star rating = 2, water star rating = 2.5, normal cycle using 16L [83]
Washing machine	N	N	N	Y	Y	Y	Y	Y	3	cycles/wk	900	Wh/cycle	5kg capacity washing machine, 3 start energy rating, warm wash cycle [74]
Dryer	N	N	N	Y	N	Y	Y	Y	2	cycles/wk	2,940	Wh/cycle	4kg capacity clothes dryer, 3 star energy rating [74]
Laptop charging	Y	Y	N	N	Y	Y	Y	Y	1	charge/day	62	Wh/full charge	See calcs in the model. Assuming Macbook Air 2022 13.6".
Phone charging	Y	Y	N	N	Y	Y	Y	Y	1	charge/day	15	Wh/full charge	See calcs in the model. Assuming Apple iPhone 14
Device charger (standby power)	Y	Y	N	N	Y	Y	Y	Y	8	hrs/day	0.3	Wh	[84]
Television (standby power)	Y	N	N	N	Y	Y	Y	Y	24	hrs/day	3	W	Standby power of a Smart TV [71]
Desktop computer monitor (standby power)	Y	N	N	N	Y	Y	Y	Y	24	hrs/day	8	W	[71]
Game console (standby power)	Y	N	N	N	Y	Y	Y	Y	24	hrs/day	6	W	Standby power [71]
Wireless modem (standby power)	Y	N	N	N	Y	Y	Y	Y	24	hrs/day	10	W	Standby power [85]
Slow cooker	Y	N	N	Y	Y	Y	Y	Y	7	hrs/week	100	Wh	[86]
HVAC:													
Portable space heater	Y	N	Y	Y	N	Y	Y	N	6	hrs/day	1,500	Wh	[70]
Reverse cycle AC (heating)	N	N	Y	Y	N	Y	Y	N	4	hrs/day	750	Wh	Assuming a COP of 4 [70]

Reverse cycle AC (cooling)	N	N	Y	Y	Y	N	N	Y	4	hrs/day	1,419	Wh	Not considering COP because figure has been reverse calculated from pricing (see calcs in the model) [70]
Wall radiator heater	Y	N	Y	Y	N	N	N	N	4	hrs/day	2,400	Wh	Assuming 100% efficiency [70]
Heated blanket	Y	N	N	N	N	N	Y	N	4	hrs/day	105	Wh	[87]
Hot water bottle	Y	N	N	N	N	Y	Y	N	1	cycles /day	183	Wh/cycle	Based on a 2200 W kettle, assuming a 5 minute boil time [88].
Pedestal fan	Y	N	Y	N	N	N	N	N	8	hrs/day	40	Wh	[89]
Ceiling fan	N	N	Y	N	Y	N	N	Y	8	hrs/day	65	Wh	[89]

Appendix 6 ECONOMIC DATA ANALYSIS INFORMATION

Table 14: Full NPV Analysis – Standardised by Lifetime

Comparison	100% Off Peak NPV	100% Shoulder NPV	50% Off Peak/ 50% Shoulder	25% Off Peak/ 75% Shoulder	25% Shoulder, 75% Off Peak	50% Shoulder/ 50% Peak	50% Peak/ 50% OffPeak	10% Offpeak	10% Shoulder
Power Point Timers	118.288	93.32732	105.8077	99.56749	112.0478	45.13414	57.61447	0.581361	0.314473
Delay Start Appliances	192.8388	139.605	166.2219	152.9134	179.5303	36.82313	63.44001	-58.1948	-58.764
Insulation Packages	254.2964	190.2492	222.2728	206.261	238.2846	66.58913	98.61273	-47.7299	-48.4148
Power Banks	-22.5484	-23.4674	-23.0079	-23.2376	-22.7782	-25.2416	-24.7821	-26.8818	-26.8916

Table 15: Full NPV Analysis - Non Standardised

Solution	100% Off Peak NPV	100% Shoulder NPV	50% Off Peak/ 50% Shoulder	25% Off Peak/ 75% Shoulder	25% Shoulder, 75% Off Peak	50% Shoulder/ 50% Peak	50% Peak/ 50% OffPeak	10% Offpeak	10% Shoulder	Minimum percent of time - offpeak	Minimum percent of time - shoulder
Power Point Timers	$580.02	$457.63	$518.83	$488.23	$549.42	$221.31	$282.51	$2.85	$1.54	0.0252	0.0317
Delay Start Appliances	$1,461.81	$1,058.28	$1,260.04	$1,159.16	$1,360.93	$279.14	$480.91	-$441.15	-$445.46	0.2549	0.3209
Insulation Packages	$753.03	$563.37	$658.20	$610.79	$705.61	$197.19	$292.01	-$141.34	-$143.37	0.1833	0.2308
Power Banks	-$66.77	-$69.49	-$68.13	-$68.81	-$67.45	-$74.75	-$73.39	-$79.60	-$79.63	6.0473	7.6134

Appendix 7 SOCIAL ANALYSIS INTERVIEW QUESTIONS

1. Tell us about yourself and the work you do.
2. What do you think drives people to be involved in the renewable energy transition?
3. Are there different barriers that different demographics face, particularly for student renters?
4. Based on your experience do you agree with our requirements?
5. Based on your research do you agree with our solutions? What are the barriers of implementation and usage?
6. What is the general attitude between renters and landlords?

Appendix 8 SOCIAL ANALYSIS SURVEY SOLUTION DESCRIPTIONS

Insulation

Home insulation is a physical barrier that is used to reduce the transfer of heat and can be installed in the walls, ceiling or on windows. It is often made of a fibrous material that traps air in small pockets to reduce convective heat transfer. Other forms of home insulation include covering surfaces in reflective material or adding another layer to windows (double glazing) with a small pocket of air in between. The insulation uses the barrier to assist in maintaining a consistent temperature inside a home, reducing the need for active heating or cooling, lowering the overall energy consumption from climate control.

Timers

Timers are devices that control the flow of electricity to an appliance, allowing you to schedule when it turns on or off. Using timers can help reduce energy consumption by ensuring appliances are only running when needed, and some can even be controlled remotely.

Heat Sensitive Laundry Timers

A heat-sensitive laundry timer is a novel device detects when sunlight is strong enough to indicate abundant solar energy on the grid. It then automatically starts your washing machine during these peak renewable energy times, even if you're not home.

Delay Timers

Delay timers are a feature in appliances like dishwashers and washing machines, allowing you to postpone their start time by several hours. By scheduling these appliances to run during off-peak hours, delay timers help shift the energy consumption to times when renewable energy is abundant.

Portable Solar Panels & Battery

A portable solar panel and battery system captures solar energy during the day and stores it in a battery for later use. This allows you to power devices like phones, laptops or small appliances using renewable energy, reducing your reliance on the grid during peak hours and lower your energy consumption when electricity is most expensive. Being portable, it can be easily moved to wherever power is needed.

Solar Hot Water

A system where water is heated directly by the sun or using electricity generated from roof-mounted solar panels.

Hot Water Storage Tank

A hot water storage tank stores hot water for use in cooking or cleaning as opposed to heating it on-demand with an instant hot water system. If the water is heated with electricity, the water can be pre-heated during the day when renewable energy is cheap and abundant rather than in the morning or evening peak demand periods.

Heat Banks

A heat bank is a device that uses electricity to heat a thermal mass, often during off-peak times when renewable energy is plentiful and cheap. It then gradually releases this stored heat into your home, providing warmth and reducing reliance on traditional heating systems during peak demand periods.

Trombe Cube

A Trombe cube is a portable, passive heating device that uses a thermal mass to absorb and store solar energy when placed in direct sunlight. Once heated, it can be moved indoors to radiate warmth into a living space, reducing the need for electric heaters and therefore lowering energy consumption.

Energy Management System

An Energy Management System (EMS) is a system that can automatically optimise a building's energy consumption in conjunction with a battery to minimise energy consumption from the grid during peak times by charging the battery during off-peak times. It can even make money by selling stored energy back to the grid at peak times when the price per kWh is highest.

Power Bank

A power bank is a portable, low voltage battery that can be used to charge handheld electronic devices.

Appendix 9 SOCIAL ANALYSIS SURVEY QUESTIONS

Q2.1 What is your age?

- 18-20
- 21-23
- 24-26
- 27+

Q2.2 What is your gender?

- Male
- Female
- Non-binary
- Prefer not to say

Q2.3 Do you come from a Culturally or Linguistically Diverse (CALD) background?

- Yes
- No
- Prefer not to say

Q2.4 Do you have any concession cards or receive any financial aid? Select all that apply.

- No concession card or financial aid
- Concession card
- Financial aid from the government
- Financial aid from the ANU
- Other (please specify) ____

Q2.5 Are you currently a student at ANU, UC, UNSW Canberra, or ACU Canberra?

- No
- Yes

Q2.6 Do you currently live within the ACT?

- No
- Yes

Q2.7 Are you renting the home you live in?

- No
- Yes

Q3.1 At what level are you studying?

- Undergraduate
- Postgraduate
- Prefer not to say

Q3.2 What is your field of study?

- Arts, Humanities and Social Sciences
- Education
- Business and Economics
- Engineering, Computer Science and Technology
- Law and Legal Studies
- Science, Health and Medicine

Q3.3 What type of residence do you live in?

- Standalone house
- Townhouse
- Apartment
- On-campus accommodation
- Other

Q3.4 How many other people do you live with?

- 0 - live alone
- 1
- 2-3
- 4+

Q3.5 What is your primary relationship to the people you live with?

- Family
- Friends
- Partner
- Strangers
- Other

Q3.6 How long have you lived in your current residence?

- Less than 1 year
- 1-2 years
- 2-4 years
- 5+ years

Q3.7 How long do you foresee yourself living in your current residence?

- Less than 1 year
- 1-2 years
- 2-4 years
- 5+ years

Q3.8 What type of hot water system do you have?

- Tank storage - gas heated
- Tank storage - electric heated
- Tank storage - solar heated
- Tank storage - heat pump heated
- Tank storage - unsure of heating type
- Instant - gas heated
- Instant - electric heated
- Instant - solar heated
- Instant - heat pump heated
- Other (please specify) ____
- Unsure

Q3.9 What heating devices do you **have** in your residence? Select all that apply.

- Gas heating
- Portable space heater
- Reverse cycle air conditioning (does heating and cooling)
- Wall heater
- Heated blanket
- Hot water bottle
- Radiator
- I don't know
- None, I don't use heating
- Other (please specify) ____

Q3.10 What heating devices do you **use** in your residence? Select all that apply.

- Gas heating
- Portable space heater
- Reverse cycle air conditioning (does heating and cooling)
- Wall heater
- Heated blanket
- Hot water bottle
- Radiator
- I don't know
- None, I don't use heating
- Other (please specify) ____

Q3.11 What cooling devices do you **have** in your residence? Select all that apply.

- Evaporative air conditioning
- Ducted/central air conditioning
- Reverse cycle air conditioning (does heating and cooling)
- Split system air conditioning (does cooling only)
- Pedestal fan
- Portable air conditioning unit
- Window air conditioning
- Ceiling fan
- I don't know
- None, I don't use cooling
- Other (please specify) ____

Q3.12 What cooling devices do you **use** in your residence? Select all that apply.

- Evaporative air conditioning
- Ducted/central air conditioning
- Reverse cycle air conditioning (does heating and cooling)
- Split system air conditioning (does cooling only)
- Pedestal fan
- Portable air conditioning unit
- Window air conditioning
- Ceiling fan
- I don't know
- None, I don't use cooling
- Other (please specify) ____

Q3.13 Which high-energy appliances do you **have** in your household? Select all that apply.

- Oven
- Electric stovetop
- Convection oven/Air fryer
- Dishwasher

- Fridge
- Washing machine
- Dryer
- Other (please specify) ____

Q3.14 Which high-energy appliances do you **use** in your household? Select all that apply.

- Oven
- Electric stovetop
- Convection oven/Air fryer
- Dishwasher
- Fridge
- Washing machine
- Dryer
- Other (please specify) ____

Q4.1 Do you believe in climate change?

- I don't believe in it
- I am indifferent
- I believe, but I think it is someone else's responsibility
- I believe, and I think it is everyone's responsibility

Q4.2 What is your highest priority about increasing renewable energy usage in your household?

- Saving money on electricity bills
- Reducing climate change
- I have no priority
- Other (please specify) ____

Q4.3 What is your biggest concern about increasing renewable energy usage in your household?

- Up-front and ongoing costs
- Lack of convenience
- Lack of comfort
- Grid instability (e.g. blackouts)
- Other (please specify) ____

Q4.4 How willing are you to shift your energy usage to time when renewable energy is more available?

- Indifferent
- Not willing
- Willing - depends on my schedule
- Very willing - I will change my lifestyle

Q4.5 What energy-saving techniques do you currently use? Select all that apply.

- Only running appliances (dishwasher, washing machine, etc.) when they are full
- Having short or cold showers to save hot water
- Turning off appliances, electronics and lights when they aren't in use
- Setting your temperature between 18-20C in winter and 25-27C in summer
- Sealing gaps around doors, windows, etc.
- Other (please specify) ____

Q4.6 What renewable technologies do you currently have in your house? Select all that apply.

- Rooftop solar panels
- Battery
- Electric Vehicle
- Solar hot water system
- Solar heat pump
- Portable solar panels

- I don't have any renewable technologies in my house
- Other (please specify) ____

Q4.7 How much do you understand the charges and/ or information on your energy bill?

- I do not understand any information
- I understand some charges
- I understand all charges
- I understand all charges and some usage information
- I understand all charges and usage information
- I do not receive an energy bill/I do not view my energy bill

Q5.1 How many days of the week are you typically home during the following times?

	0 1 2 3 4 5 6 7
7am - 9am	
9am - 1pm	
1pm - 6pm	
6pm - 9pm	
All day	

Q5.2 Are you willing and/or able to use these solutions?

Q5.3 Rank how likely you are to install and use these solutions?

Q5.4 Would you purchase these solutions based on the price?